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THE DEPOSITIONAL HISTORY OF THE UPPER GIVETIAN SLAVE POINT FORMATION AT SAWN LAKE FIELD, ALBERTA, CANADA

by

©

HOLLY K. RADDYSH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF **MASTER OF SCIENCE**

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

FALL 1992

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THE DEPOSITIONAL HISTORY OF THE UPPER GIVETIAN SLAVE POINT FORMATION AT SAWN LAKE FIELD, ALBERTA, CANADA submitted by HOLLY K. RADDYSH in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in GEOLOGY.

Supervisor: B. Jones

B. D. E. Chatterton

C. R. Stelck

D. Lubell

Date: Sept. 14, 1992

ABSTRACT

THE DEPOSITIONAL HISTORY OF THE UPPER GIVETIAN SLAVE POINT FORMATION AT SAWN LAKE FIELD, ALBERTA, CANADA

Detailed study of log markers (550 logs) and facies variations (50 cores) have revealed that the upper Givetian Slave Point Formation at Sawn Lake consists of 5 depositional units (Divisions A to E). These depositional units represent development of an isolated reef on top of a carbonate platform.

The lowest depositional unit, Division A, represents aggradation of the Slave Point Formation carbonate platform. The platform is overlain by Division B, a stromatoporoid and coral shoal that is confined to the Sawn Lake field area. Overlying the carbonate shoal is Division C, representing the initiation and aggradation of an isolated reef. Aggradation of Division C is disrupted by a relative sea level rise that exceeded the growth potential of the slowly aggrading reef flat and foreslope environments. Deposition of Division D followed with continued aggradation of the isolated reef. Termination of the isolated reef is represented by deposition of the deeper-water facies of Division E. Basin filling with marine calcareous shales (Waterways Formation) terminated deposition of Division E.

The highest porosities occur in the reef flat, reef margin and upper foreslope of the isolated reef (Division C and D) where they consist of matrix-supported peloidal-grainstones.

ACKNOWLEDGEMENTS

I wish to thank Dr. Brian Jones, my thesis advisor, who provided invaluable guidance, editorial assistance, and endless encouragement throughout the project. I also acknowledge the operating grants awarded to Dr. B. Jones by the Natural Science and Engineering Research Council. I would also like to thank Dr. S. G. Pemberton for his initial interest and assistance in the study. Thanks also goes to my committee members Dr. B. D. E. Chatterton, Dr. C. R. Stelck, and Dr. D. Lubell who provided me with helpful suggestions and ideas.

A special thanks goes to Jack Wendte for his suggestion of the study area and assistance with core examination. Dr. Wendte's keen interest in the project and never-ending willingness to discuss Devonian carbonates was of great benefit. My sincerest thanks to Walter Keith for his encouragement, suggestions and the sharing of his ideas on regional Devonian stratigraphy.

Much gratitude goes to the Alberta Research Council (ARC) and particularly Shaun O'Connell for arranging financial and technical support for this project. This study was part of the ARC's Peace River Arch Project and would not have been possible without Shaun's keen interest and willingness to help. I also acknowledge Dr. Jan Boon and other ARC employees for their interest and support in the study. The ARC also provided assistance with drafting of cross-sections and maps. I would also like to thank Jim Underschultz (ARC) for his expert computer assistance and production of maps.

I gratefully acknowledge support from my employer, Suncor Resources Group and particularly Rob Edge (Suncor Inc.) for his expert drafting of

colour figures and Ken Hryciw (Suncor Inc.) for computing assistance. I sincerely thank Dr. Tim Marchant of Amoco Canada for arranging use of petrographic thin sections. I acknowledge initial support in the form of basemaps provided by Geoff Burrowes, originally with Gulf Canada Resources.

The ideas presented in this thesis were stimulated by conversations and technical advice from fellow graduate students at the University of Alberta. In particular I would like to thank Bruce Beynon and Ian Hunter. Bruce also provided much technical support in the form of drafting and editorial assistance. I would also like to thank Elsie Tsang (University of Alberta) for her assistance throughout the project.

I would especially like to thank my parents, Alexandra and Tony Raddysh for their endless encouragement, love and financial assistance. I am also grateful for the support and encouragement from other family members including Joan, Marjorie, Lora, Bill, Andy and Kim. Lastly, I am indebted to Bruce Beynon for his friendship throughout this study. His unending support, love and encouragement were invaluable in the completion of the project.

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CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

The Slave Point Formation is an important producer of light gravity oil in the Peace River arch area of north-central Alberta. The hydrocarbon bearing carbonates of the Slave Point Formation are developed on an arcuate trend as isolated carbonate buildups along the eastern side of the Peace River arch. Exploration and development drilling of Slave Point fields peaked during the 1980's. This wealth of data revealed much new information about Slave Point fields, little of which has been documented to date. The objective of this study is to determine the geometry of the reservoir and depositional history of the Slave Point Formation at Sawn Lake field. This analysis can contribute to an understanding of the heterogeneity of the reservoir and be utilized in the exploration, planning and implementation of hydrocarbon recovery programs in similar carbonate buildups.

The Sawn Lake field covers approximately 32 square kilometres and includes the "A", "J", "K", "L", and "M" pools. The "J" pool has the largest area (26 square kilometres) and about 80% of the reserves. The total recoverable reserves from the five pools are estimated at 5.8 Million barrels oil (MMBO) of which approximately 2.5 MMBO have been produced (ERCB, 1990). The field is presently undergoing secondary hydrocarbon recovery.

1.2 STUDY AREA

The study incorporates 99 townships, extending from Twp 87 to Twp 95 between Rge 8W5 and Rge 18W5 (Fig. 1.1). Geophysical well logs were examined over this area for correlation and mapping of stratigraphic markers. Core was examined over the Sawn Lake field and off-field area covering nine townships, extending from Twp 90 to Twp 92, between Rge 11W5 and Rge 13W5 (Fig. 1.1). The Sawn Lake field is located approximately 400 km northwest of Edmonton.

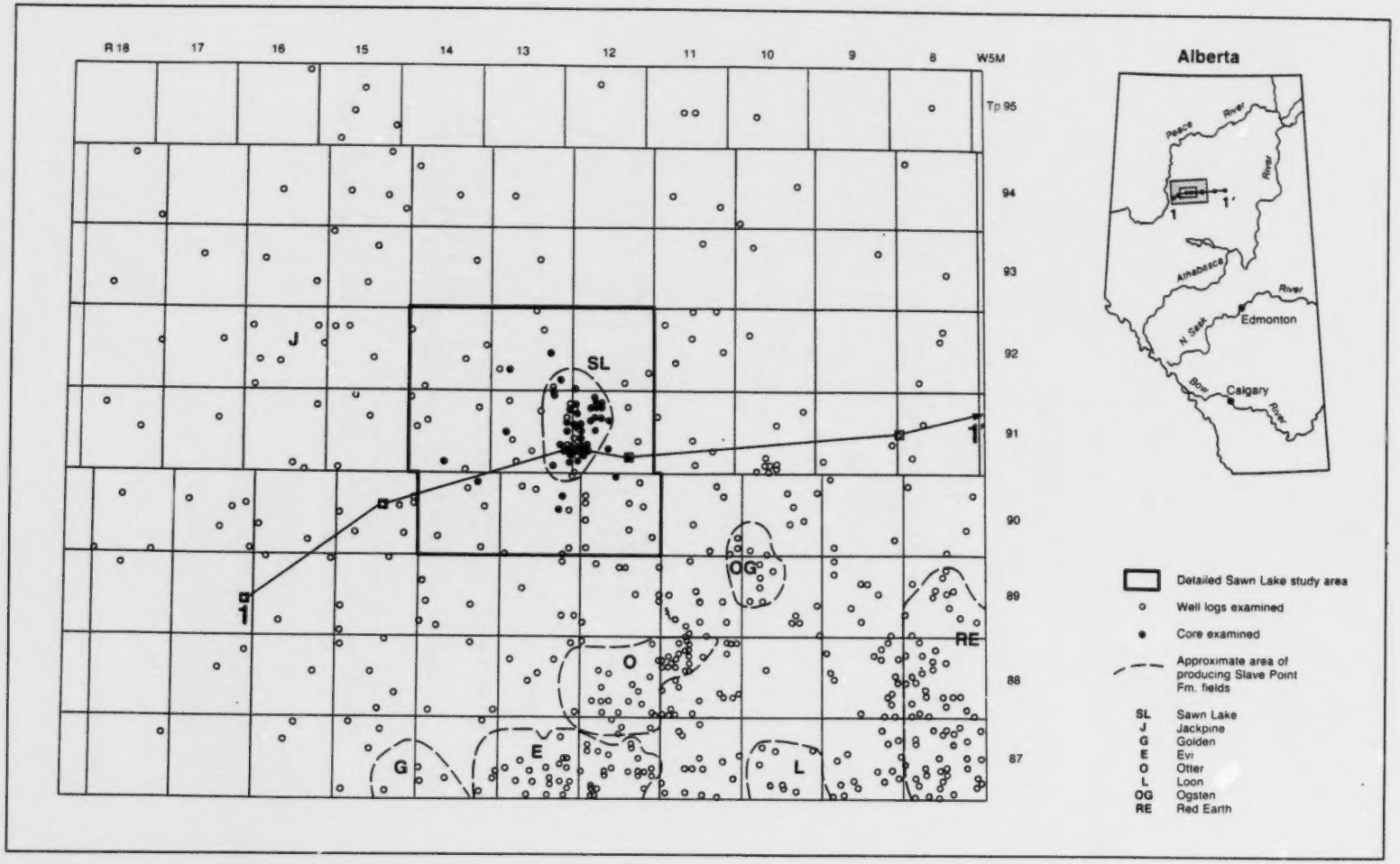
1.3 OBJECTIVES

The Sawn Lake field was chosen for a detailed core study because: (1) the limestone field has good preservation of organic and inorganic components, (2) practically all on-field wells are cored, and (3) the recent discovery date (1984) of the field provides a full suite of high-quality well-logs. This study does not attempt to resolve stratigraphic or nomenclatural problems of the Slave Point Formation which have been dealt with in studies by Stoakes (1988) and Keith (1990).

A detailed examination of cores and geophysical well-logs was conducted in order to: (1) determine the structural and stratigraphic position of the Slave Point Formation at Sawn Lake field, (2) define the sedimentary facies and facies relationships in the Slave Point Formation, (3) determine the lateral and vertical extent of these facies, and (4) determine the depositional history of the Slave Point Formation.

Figure 1.1

Study area location map illustrating core and log control utilized in the study of the Slave Point Formation. The Sawn Lake field (SL) is located in the central portion of the map. Note the scarcity of core data beyond the northeastern, northwestern and western margin of Sawn Lake. Other Slave Point Formation fields are located to the south and northwest of Sawn Lake. Also note location of stratigraphic cross-section 1-1'.


R 18
17
16
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10
9
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W5M
Tp 95
94
93
92
91
90
89
88
87
J
SL
OG
O
RE
G
E
L
1
1'
Alberta
Peace River
Athabasca River
N. Sask. River
Edmonton
Calgary
Bow River
Detailed Sawn Lake study area
Well logs examined
Core examined
Approximate area of producing Slave Point Fm. fields
SL Sawn Lake
J Jackpine
G Golden
E Evi
O Otter
L Loon
OG Ogsten
RE Red Earth

1.4 METHODOLOGY

The data base for this study includes 550 well logs and 50 measured core (Fig. 1.1). Of the measured core approximately 40 are from Sawn Lake on-field wells and 10 are from off-field wells.

Well-logs consisting mainly of resistivity, sonic, gamma, and neutron-density profiles, were examined for the purpose of correlation of stratigraphic markers and facies characteristics, including shale content and porosity. The sedimentary facies identified in core could not be identified by well-log response because a unique well-log shape did not correspond to a particular facies. Only the datum (top of the Fort Vermilion Formation) and top of the Slave Point Formation were easily recognizable on well-logs.

Core measurement entailed identification of organic constituents, sedimentary structures, sedimentary textures, and lithology. Each core was measured in metric units and were compared to the core analysis for correlation of porosity and permeability. Recognition of constituents was aided with a hand lens and binocular microscope. The cored interval of the Slave Point Formation ranged from 15 to 25 m. The core, commonly unslabbed, was 9 cm in diameter.

One hundred and twenty thin sections, obtained on loan from Amoco Canada Ltd., were examined petrographically. These thin sections had been stained with a dual Alizarin Red and potassium ferricynide stain. Due to a technical problem with the staining, both stains were faint to non-detectable on most thin sections. For example, some calcite crystals had a very light pink colouring whereas similar crystals were left unstained. This made it difficult or impossible to distinguish calcite from dolomite and ferroan calcite from non-ferroan calcite. To

distinguish these basic components approximately 15 hand samples, obtained from the same interval as some of the thin-sections, as well as a few re-etched thin sections were dual stained following the procedure recommended by Dickson (1965). This allowed differentiation of calcite from dolomite; however, ferroan calcite was still difficult to distinguish from non-ferroan calcite.

1.5 TERMINOLOGY

Terms used in this study are briefly reviewed because environmental terms describing carbonate sediments commonly have more than one definition. A **carbonate ramp** refers to a huge carbonate body built away from positive areas and down gentle regional paleoslopes (Wilson, 1975). A **carbonate platform** is defined as a huge carbonate body having a horizontal top, abrupt shelf margins and surrounded on all sides by deep water and/or attached to a continent on one side (James, 1987). A **carbonate buildup** is defined as a body of locally formed (laterally restricted) carbonate sediment which possesses topographic relief and differs from thinner deposits of surrounding and overlying rocks (Heckel, 1974; Wilson, 1975). The term **reef** refers to a layered, laterally restricted carbonate buildup which formed *in situ*, possessed topographic relief, was potentially wave resistant and was stabilized syndepositionally by organic growth and/or submarine cementation (James, 1987). The term **reef complex** refers to a major carbonate mass consisting of reef(s) and reef-associated sediments which is commonly divisible into several facies or zones (James, 1987). The term **shoal** refers to an accumulation of unconsolidated sediment and organic fragments that rises from the bed of a body of water to the near

surface (Bates and Jackson, 1980).

1.6 CLASSIFICATION OF SAWN LAKE LIMESTONES

Limestones in the Slave Point Formation at Sawn Lake range from mudstones to bindstones (Embry and Klovan, 1971). The limestones, formed primarily of coarse reef derived components, are classified according to the scheme outlined by Embry and Klovan (1971) (Fig. 1.2). The visual percentage comparison charts in Terry and Chilingarian (1955) were used to estimate the proportion of carbonate grains and fragments.

The limestones in the study area include a variety of constituents. The constituents are composed of allochems (carbonate grains or particles) and carbonate cements (micrite, spar calcite, and saddle dolomite). Skeletal grains were derived from the biological or mechanical breakdown of stromatoporoids, corals, brachiopods, crinoids, and gastropods. Accessory minerals which comprise less than 2% of the rock, include pyrite, quartz, and chalcedony.

The terms micrite and spar calcite are used here following the definition of Folk (1959, 1962, 1965). Unlike Folk, however, these terms are used with no genetic connotations. The term saddle dolomite is used after the definition of Radke and Mathis (1980). They suggested that saddle dolomite is an indicator of higher diagenetic temperatures and is associated with sulfide mineralization and hydrocarbon occurrences. In the Slave Point Formation saddle dolomite is typically characterized by sweeping extinction in cross-polarized light, curved or saddle-shaped crystal faces, opaque white colour and a coarse crystal size. This cement typically occludes shelter cavity porosity.

Stylolites, which are common in the Slave Point Formation at Sawn

<table>
<tr><th colspan="6">ALLOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS NOT ORGANICALLY
BOUND DURING DEPOSITION</th><th colspan="3">AUTOCHTHONOUS LIMESTONES
ORIGINAL COMPONENTS ORGANICALLY
BOUND DURING DEPOSITION</th></tr>
<tr><td colspan="4">LESS THAN 10% > 2mm COMPONENTS</td><td colspan="2" rowspan="2">GREATER THAN
10% > 2mm
COMPONENTS</td><td rowspan="3">BY
ORGANISMS
WHICH
ACT AS
BAFFLES</td><td rowspan="3">BY
ORGANISMS
WHICH
ENCRUST
AND
BIND</td><td rowspan="3">BY
ORGANISMS
WHICH
BUILD
A RIGID
FRAMEWORK</td></tr>
<tr><td colspan="3">CONTAINS LIME MUD (< .03mm)</td><td>NO
LIME
MUD</td><td rowspan="2">MATRIX
SUPPORTED</td><td rowspan="2">>2mm
COMPONENT
SUPPORTED</td></tr>
<tr><td colspan="2">MUD SUPPORTED</td><td colspan="2" rowspan="2">GRAIN
SUPPORTED</td></tr>
<tr><td>LESS THAN
10% GRAINS
(>.03mm <2mm)</td><td>GREATER
THAN 10%
GRAINS</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>MUD -
STONE</td><td>WACKE -
STONE</td><td>PACK -
STONE</td><td>GRAIN -
STONE</td><td>FLOAT -
STONE</td><td>RUD -
STONE</td><td>BAFFLE -
STONE</td><td>BIND -
STONE</td><td>FRAME -
STONE</td></tr>
</table>

Figure. 1.2 Classification of limestones (from Embry and Klovan, 1971)

Lake, are classified according to the scheme of Flügel (1982, p.93). Stylolites are herein defined as "thin zones of discontinuity in rocks" which have an "undulate to zig-zag" shape (Flügel, 1982). Stylolites are important because they reduce both the original thickness of sediment in a vertical direction and the vertical permeability. In the limestones, stylolites are columnar; high and low amplitude peaks (up 2 cm); irregular; and horsetail. Both parallel and irregular anastomosing stylolite sets are common. A "microstylolite" is a very thin undulating surface with a relief in the order of only 20 to 40 microns (Wanless, 1979). A microstylolite swarm refers to an anastomosing accumulation of microstylolites.

Peloids are locally abundant in the limestones of the Slave Point Formation and are commonly associated with the matrix-supported facies. The term peloid is herein defined as an ovoid body of aphanitic limestone (Mckee and Gutschick, 1969).

Oncoids are herein used to define algal-coated grains that generally are over 2 mm in diameter and have a coating consisting of irregular or crinkly layers (Wilson, 1975). In the Slave Point Formation, oncoids consist of irregular non-concentric micritic layers surrounding a nucleus commonly composed of gastropod or stromatoporoid fragments. They are often associated with sediments containing bored and abraded nodular and bulbous stromatoporoids. Their formation must be attributed to turbulence of sufficient strength to allow regular overturning of the oncolite on the sediment-water interface.

Intraclasts are herein referred to as sand-size or larger nonskeletal particles that are broken from consolidated or hardened carbonate materials that are accumulating within the basin of deposition

(Friedman and Sanders, 1978).

Hardgrounds are common in the Slave Point Formation of the Sawn Lake field. The term "hardground" applies to a synsedimentary lithified surface in marine limestones that have been exposed on the sea floor (Kennedy and Garrison, 1975). The recognition of hardgrounds is based on biological, diagenetic, and physical features. The biological recognition of hardgrounds is based primarily on the presence of boring and encrusting fauna (Goldring and Kazmierczak, 1974). These fauna represent the omission and postomission trace fossil suites of Bromleys's (1975) classification. Hardground shape is generally described as planar or hummocky (Bromley, 1975).

1.7 PALEONTOLOGY AND PALEOECOLOGY

The main fossil types found in the study area include stromatoporoids, corals, bivalves, brachiopods, crinoids, and gastropods. In general, fossils are referred to by the common faunal name and not specific genera. An exception is the genus *Amphipora*, used herein to refer to small branching stromatoporoids. The relative quantity of fossils are described using such terms as abundant (greater than 75%), common (40 to 75%), sparse (1 to 40%), and absent (0%). The modes of growth, preferred associations with other organisms and sediments, as well as areal and stratigraphic distribution of fossil organisms aided in the determination of depositional environments.

Stromatoporoids are the dominant organic component of the Sawn Lake carbonate buildup and are classified according to shape. Stromatoporoids, now extinct, are considered to be sponges based on

their similarities to the modern sclerosponges. These benthonic, sessile, marine organisms are found mainly in reef limestones (Fischbuch, 1968). The stromatoporoids are divided into: spherical, cylindrical, tabular, wafer, and irregular types.

1.7.1 Major Constituents

Spherical stromatoporoids are subdivided on the basis of their size, into nodular (less than 3 cm), bulbous (3 to 10 cm), hemispherical (10 to 15 cm) and massive (greater than 15 cm) forms. The maximum size of the hemispherical and massive stromatoporoids is limited by the core diameter. The growth position of subspherical stromatoporoids cannot be determined because attachment sites were not observed. The spherical stromatoporoids are surrounded by a matrix that varies from carbonaceous mudstone and wackestone to packstone and minor grainstone. They are commonly associated with cylindrical stromatoporoids and *Amphipora*. Nodular stromatoporoids (less than 3 cm) and bulbous stromatoporoids (3 to 10 cm) are commonly fragmented, encrusted, and/or bored.

Cylindrical stromatoporoids (diameter from 4 to 10 mm), also referred to as dendroid or branching forms are identified in the Middle Devonian as *Stachyodes* and *Idiostroma* (Craig, 1987).
Their original length cannot be determined because only fragments of the cylindrical stromatoporoids are preserved. Cylindrical stromatoporoids are typically associated with branching corals and subspherical stromatoporoids.

Amphipora refers to delicate branching stromatoporoids (0.2 to 0.5 cm in diameter). This form is smaller in diameter and lacks the

well-organized lamellar structure of cylindrical stromatoporoids. *Amphipora* are probably not preserved in growth position due to their delicate structure.

Tabular stromatoporoids are plate-like in form and are divided into "wafer" (0.5 to 2.0 cm) and "thick tabular" (greater than 2 cm) forms. Wafer stromatoporids are commonly fragmented whereas thick tabular stromatoporoids encrust and bind one on top of the other, indicating an *in situ* formation. The tabular stromatoporoids are associated with irregular, cylindrical, and hemispherical stromatoporoids.

Irregular stromatoporoids constitute those stromatoporoids which are encrusting and have an irregular shape (less than 4 cm in diameter). They are identified by alternating light and dark wavy layers (1 to 3 mm in thickness) which have encrusted around a fossil fragment. They are associated with tabular and hemispherical stromatoporoids.

Branching corals (0.5 to 1.5 cm diameter) or finger tabulate corals are abundant in the Slave Point Formation and are identified in the Middle Devonian as *Thamnopora* (Craig, 1987). Solitary forms are referred to as rugose corals and are volumetrically insignificant in the Slave Point Formation at Sawn Lake field. The branching corals are commonly associated with cylindrical stromatoporoids and occur in bituminous wackestones and packstones.

1.7.2 Minor Constituents

Brachiopod valves (1 to 3 cm long) commonly occur in mudstones and packstones. They are associated with crinoids, but, appear to be more widespread.

Crinoid ossicles (0.3 to 0.5 cm diameter) occur in wackestones to

packstones of the Slave Point Formation. They are associated with cylindrical and tabular stromatoporoids.

Molluscs in the Slave Point Formation include gastropods, bivalves, and cephalopods. Molluscs are commonly preserved as calcite spar-filled molds; the original shell structure was probably in part aragonitic. Boring bivalves cross-cut and extend into hardground surfaces. Rare nautiloid cephalopods (3 to 7 cm long) occur in fossiliferous wackestones and packstones.

Microfossils, generally less than 0.2 cm in length, include molluscs and calcispheres. Ostracodes are less than 0.1 cm and pelecypods have thin shells. Other molluscs include *Tentaculites* and *Styliolina*. In longitudinal section, the conical shell of *Tentaculites* has an outer layer which is serrated and an inner layer which has concentric rings or septa. *Styliolina*, also has a conical shell but possesses a smooth, unchambered shell without concentric rings. Calcispheres are small (0.01 to 0.04 mm diameter), hollow, spherical bodies with a thin (less than 0.001 mm) granular wall.

Algae commonly encrust nodular and bulbous stromatoporoids and branching corals. Microscopic filaments include the blue-green alga *Girvanella*, characterized by entwined tubular filaments and the green alga *Hedstroemia*, characterized by rounded masses consisting of a radial arrangement of branching tubes.

CHAPTER 2: REGIONAL STRATIGRAPHY

2.1 STRATIGRAPHIC SETTING

2.1.1 Introduction

The Slave Point Formation, of the Beaverhill Lake Group, is a widespread carbonate unit deposited in the Western Canada sedimentary basin. The Western Canada sedimentary basin limits are the miogeocline edge to the west, the Tathlina Arch to the north, the Devonian erosional edge to the east, and the central Montana Arch to the south (Fig. 2.1). The Devonian erosional edge formed during several Paleozoic, Mesozoic, and Cenozoic erosional events (Podruski *et al.*, 1988).
Deposition of the Slave Point Formation was influenced by the Tathlina, Peace River, and West Alberta Arches (Fig. 2.1).

The Peace River Arch is situated between the eastern edge of the Cordillera in northern British Columbia extending through to northwestern Alberta. The elongated east-northeast trending Arch is bound to the north by the Hay River Basin and to the south by the Elk Point Basin (Bassett and Stout, 1968). The Peace River Arch was an elevated mass of Precambrian rock that was uplifted in early Paleozoic time and remained exposed as a granite landmass during deposition of the Slave Point Formation (Cant, 1988). This Arch was tectonically active during the Paleozoic and early Mesozoic and influenced Slave Point Formation sedimentation (Keith, 1990). Tectonic activity formed a complex series of small tilted fault blocks trending both parallel (southwest-northeast) and perpendicular (northwest-southeast) to the axis of the Arch (Podruski *et al.*, 1988). These fault blocks, originating in the Precambrian, were expressed as paleotopographic highs

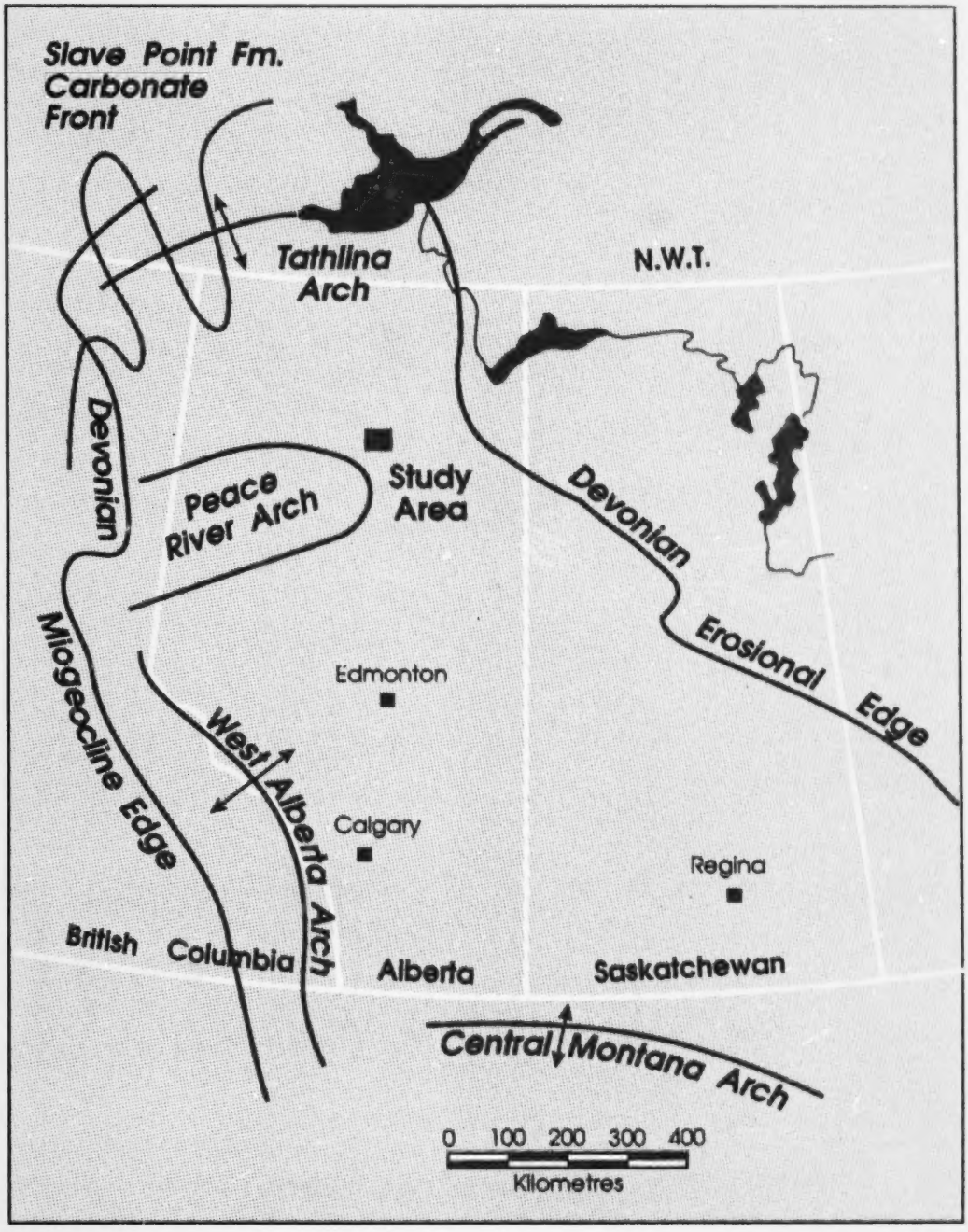


Figure 2.1 Principal Devonian tectonic elements, Western Canada Sedimentary Basin (modified from Bassett and Stout, 1968)

at the pre-Slave Point Formation surface. The topographically higher areas would have been shallower and, therefore, more likely to allow the initial establishment and growth of reef-type organisms (Craig, 1987; Davies and Tooth, 1987; Dunham *et al.*, 1983; Gosselin and Smith, 1987a; Gosselin *et al.*, 1989; Podruski *et al.*, 1988; Ferry, 1989).

2.1.2 Beaverhill Lake Group

The "Beaverhill Lake" Formation was initially proposed by the Geological Staff of Imperial Oil (1950) for 220 m of limestones and calcareous shales in the type section, 11-11-50-17W4 (Fig. 2.2). The lowermost Fort Vermilion and Slave Point formations and members of the Waterways Formation comprise the Beaverhill Lake Formation following the usage by the "Committee on Slave Point and Beaverhill Lake Formations" (1964). From a northeastern British Columbia study area, Griffin (1965) divided the Beaverhill Lake Formation into the "Upper Beaverhill Lake" unit consisting of the Mildred, Moberly, and Christina members and a "Lower Beaverhill Lake" consisting of the Calumet and Firebag members. The Beaverhill Lake Formation was elevated to group status by Leavitt and Fischbuch (1968); a scheme that is the presently accepted nomenclature for the study area (Fig. 2.2).

The Beaverhill Lake Group consists of a series of carbonates and shales of marine origin deposited on a shallow shelf in a moderately subsiding basin (Keith, 1990). The Beaverhill Lake Group is characterized by a wedge-shaped profile which is thick in the basin (Twp 93 Rge 2W5) and gradually thins west towards the Arch (Twp 89 Rge 2W5) (Fig. 2.3). The Beaverhill Lake Group is underlain by the Middle

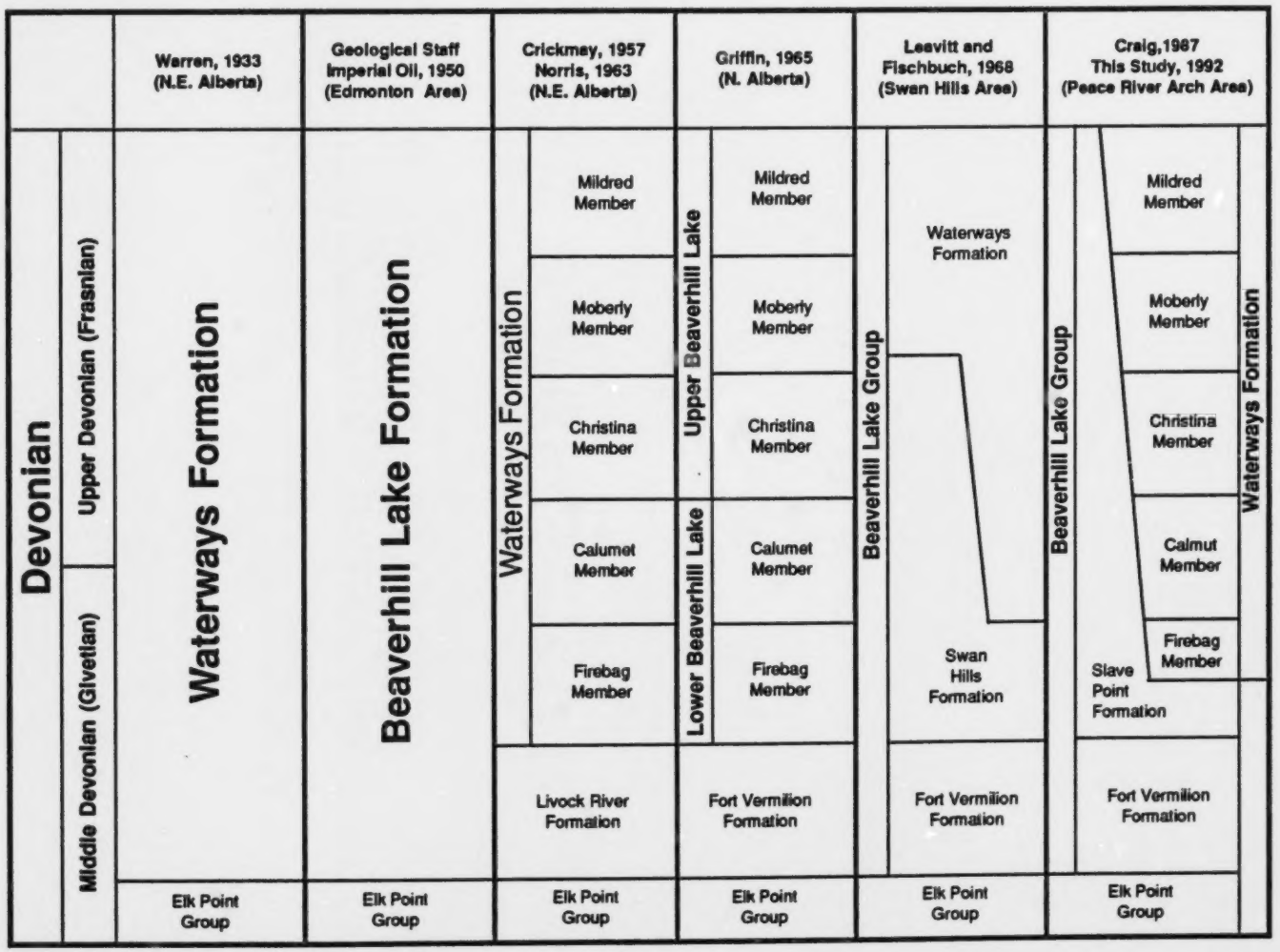


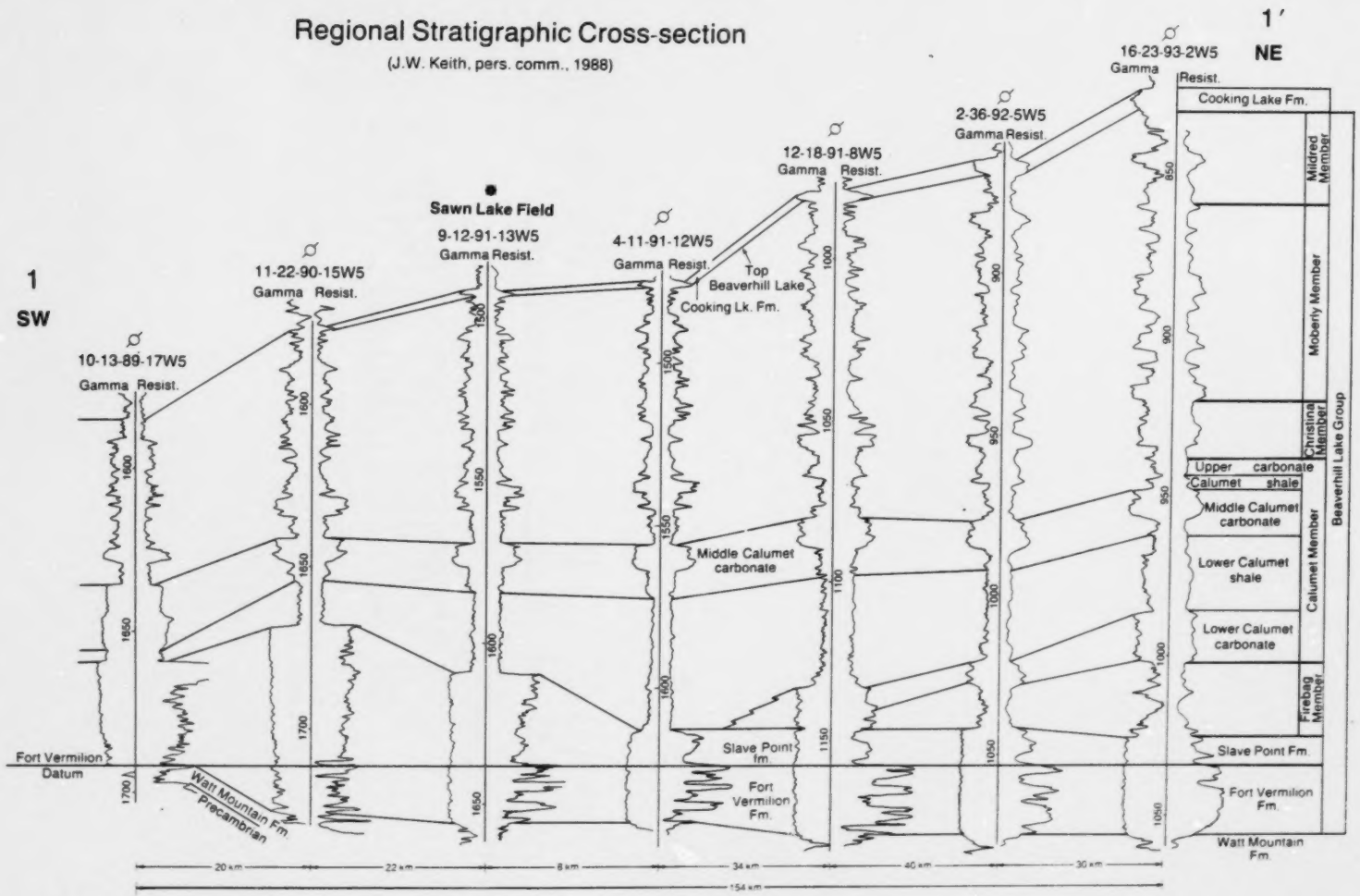
Figure 2.2 History of stratigraphic nomenclature in the study area.

Figure 2.3

Regional stratigraphic cross-section 1-1' illustrating the subdivision of the Beaverhill Lake Group into the Fort Vermilion, Slave Point and Waterways formations. The gamma ray log is displayed on the left track and the induction log is displayed on the right track. Depths are in meters. Note the thickening of the Beaverhill Lake Group towards the northeast. The Slave Point Formation is notably thicker at the location of the Sawn Lake field (9-12-91-13W5).

Regional Stratigraphic Cross-section

(J.W. Keith, pers. comm., 1988)



Devonian Elk Point Group and overlain by the Upper Devonian Woodbend Group. Regionally the group extends from northeastern British Columbia, southern Northwest Territories, through Manitoba, Saskatchewan, Alberta, Montana, and North Dakota.

2.1.3 Fort Vermilion Formation

The Fort Vermilion Formation, originally designated as the "Fort Vermilion anhydrite member" was proposed as a part of the basal portion of the Slave Point Formation (Law, 1955). In the type section (Hudson's Bay 1-32-104-8W5), at a depth of 701 to 737 m, the Fort Vermilion Formation is characterized by a brown to white anhydrite, containing interbeds of dolomite and limestone (Law, 1955). The Fort Vermilion anhydrite member was raised to formation status by Norris (1963) who recognized its widespread occurrence in northeastern Alberta.

The Fort Vermilion Formation ranges in thickness from 6 m south of the Tathlina Arch (Belyea and Norris, 1962) to 23 m in the Peace River Arch area (Norris, 1963) to 37 m north of the Swan Hills area (Hemphill *et al.*, 1970). Away from the Peace River Arch the Fort Vermilion Formation consists of thick beds of dolomitic mudstone and anhydrite separated by thin shales. In northern Alberta, west of the sixth meridian, the Fort Vermilion Formation anhydrites are replaced by open-marine basinal carbonates that are indistinguishable from the Slave Point Formation carbonates (Crawford, 1972). South of the Arch, the Fort Vermilion Formation is replaced by Slave Point Formation carbonates just beyond the eastern margin of the Swan Hills reef development (Norris and Uyeno, 1983). The Fort Vermilion Formation thins toward and terminates by onlapping the Peace River Arch (Keith, 1990). The Fort

Vermilion Formation conformably overlies the Watt Mountain Formation in the study area. In the Peace River Arch area the Fort Vermilion Formation directly overlies the Watt Mountain Formation, the Gilwood Member, the Granite Wash, or the Precambrian basement.

The contact between the Fort Vermilion Formation and the overlying Slave Point Formation is conformable in northwestern Alberta (Featherstone, 1982; Norris and Uyeno, 1983) but unconformable in northeastern Alberta (Crickmay, 1957; Park and Jones, 1985). A conformable contact between these formations in northwestern Alberta is identified by the absence of deformation at the contact (Featherstone, 1982; Norris and Uyeno, 1983).

The Fort Vermilion Formation is regarded as Middle Devonian in age based on its stratigraphic position which is above the Watt Mountain Formation and equivalent beds and below the Slave Point Formation (Norris, 1963).

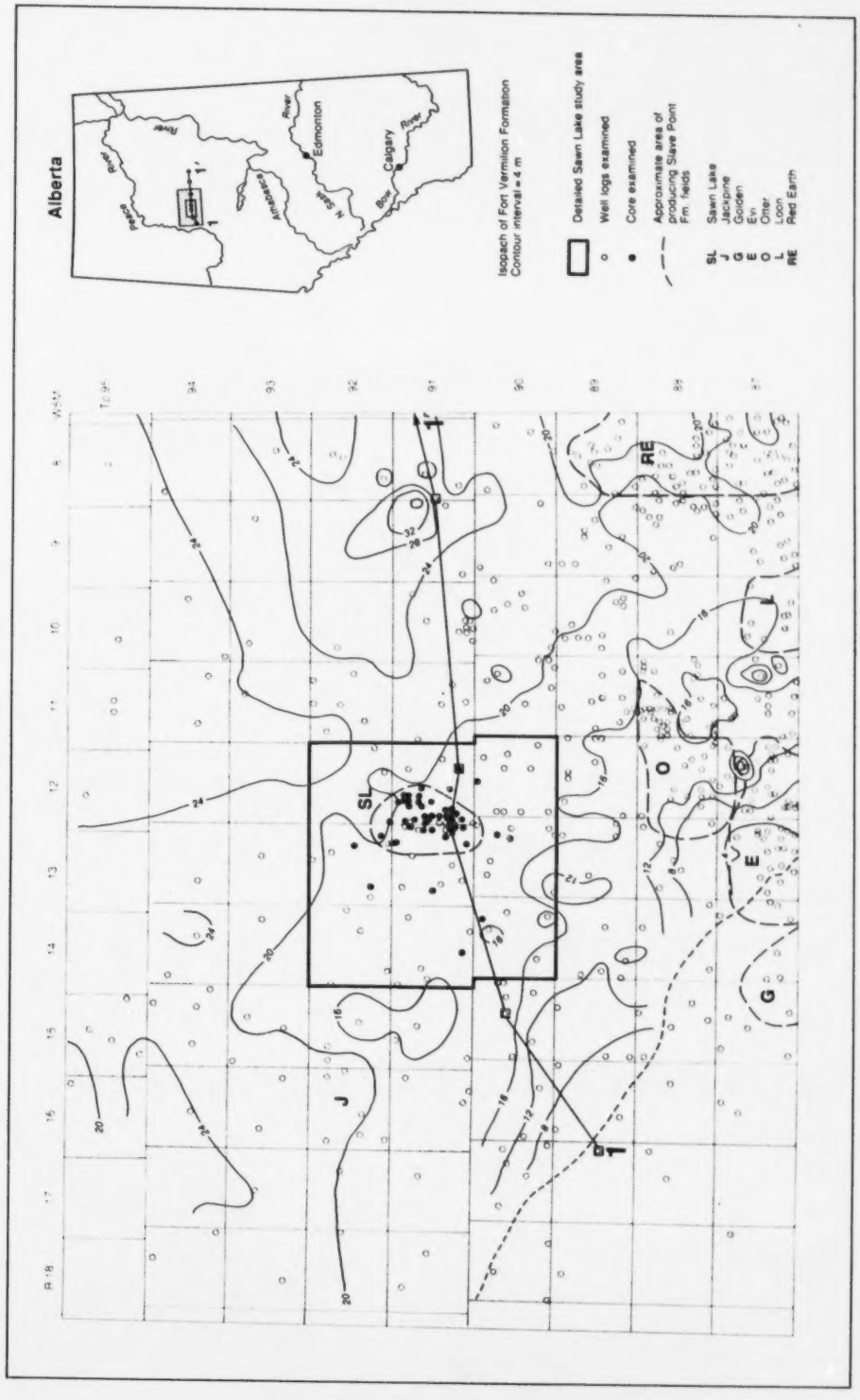
The datum used throughout this study is the top of the Fort Vermilion Formation and its usage is based on the following criteria: (1) the formation represents deposition of evaporites and dolomites in a shallow, intertidal to supratidal environment (Craig, 1987) which suggests that deposition took place very close to sea-level, resulting in a flat, planar surface, and (2) the formation is a relatively constant thickness over the Sawn Lake field reflecting a flat, planar surface. Across the Sawn Lake field, the Fort Vermilion Formation has a constant thickness of approximately 20 m (Fig. 2.4).

2.1.4 Slave Point Formation

Cameron (1918) introduced the term "Slave Point limestones" for 61 m

Figure 2.4

Isopach map of the Fort Vermilion Formation. Note the gradual thinning towards the southwest corner of the map. The dashed line, striking northwest-southeast, in the southwest corner is the zero edge of the Fort Vermilion Formation. The contour interval is 4 meters.


Alberta
Peace River
Athabasca River
N. Sask. River
Edmonton
Bow River
Calgary
1
1'
Isopach of Fort Vermilion Formation
Contour interval = 4 m
Detailed Sawn Lake study area
Well logs examined
Core examined
Approximate area of producing Slave Point Fm. fields
SL Sawn Lake
J Jackpine
G Golden
E Ev
O Otter
L Loon
RE Red Earth
SL
J
G
E
O
L
RE
1
1'

of grey brown, thinly bedded, fossiliferous and bituminous limestones and interbeds of calcareous shale that outcrop along the west arm of the north and south shore of Great Slave Lake. Campbell (1950, 1957) divided the Slave Point Formation into a lower argillaceous, fossiliferous limestone unit, a middle fragmental unit, and an upper stromatoporoidal unit. He recognized a 3 m thick dark-greenish gray shale 9 m above the base of the Slave Point Formation which he called the "Amco shale". Law (1955) extended the Slave Point Formation from outcrop at Slave Point, in the Great Slave Lake area, into the subsurface of northwestern Alberta. Law (1955) defined the Slave Point Formation in the reference well (2-22-117-5W6) between 1301 to 1357 m and proposed that the formation be divided into the lower Fort Vermilion Member and an upper, unnamed member. He suggested that the Slave Point Formation should be restricted to the beds between the Amco shale designated by Campbell (1950) and the upper Devonian shale unit. Law (1955) correlated the upper part of Campbell's (1950) lower unit and the Amco shale with the Watt Mountain Formation.

A buff coloured 1.7 m thick limestone bed, overlying anhydrite of the Elk Point Formation in the McMurray area of northeastern Alberta, was assigned to the Slave Point Formation (Crickmay, 1957). The limestone bed did not correlate with the Slave Point Formation and instead was termed the "Livock River Formation" by Norris (1963). This terminology is no longer used because the Slave Point Formation was regionally correlated in the subsurface from northeastern British Columbia across northern Alberta to the McMurray area (Griffin, 1965).

Deposition of the Slave Point Formation was initiated during a marine transgression that resulted in the development of an extensive

reef-rimmed carbonate platform (Fig. 2.5). The development of isolated carbonate reefs occurred in response to minor sea level oscillations (Harvard and Oldershaw, 1976). The Slave Point Formation is 20 to 35 m thick along the flanks of the Alberta Ridge and the Peace River Arch area (Burrowes and Krause, 1987). To the north and northwest of the Peace River Arch area the Slave Point Formation thickens to 150 m along the Shekilie Barrier reef complex (Burrowes and Krause, 1987). Throughout northeastern British Columbia the Slave Point Formation is 61 m to 152 m thick (Norris and Uyeno, 1983). At Sawn Lake field, the Slave Point Formation ranges in thickness from 13 to 30 m (Fig. 2.6).

The Slave Point Formation limestones and dolostones are replaced by open marine shales along a linear front, termed the "Slave Point Formation carbonate front", which trends north-northeast in northeastern British Columbia and the southern Northwest Territories (Griffin, 1965) (Fig. 2.1). The carbonate front was controlled by the Shekilie-Pine Point barrier of the Upper Keg River Formation and the Pine Point and Sulphur Point formations. Marine calcareous shales were eventually deposited over the barrier into northern and central Alberta in early Frasnian time.

The contact between the Slave Point Formation and the overlying Upper Devonian strata is typically unconformable. In northeastern British Columbia and northwestern Alberta, the Slave Point Formation is unconformably overlain by black bituminous shales of the Muskwa and Waterways formations (Griffin, 1965; Hriskevitch, 1970). In northern Alberta, Featherstone (1982) found 1 to 1.5 ostracode biozones missing at the unconformable contact between the Slave Point and Waterways formations. In northeastern Alberta the Peace Point Member of the

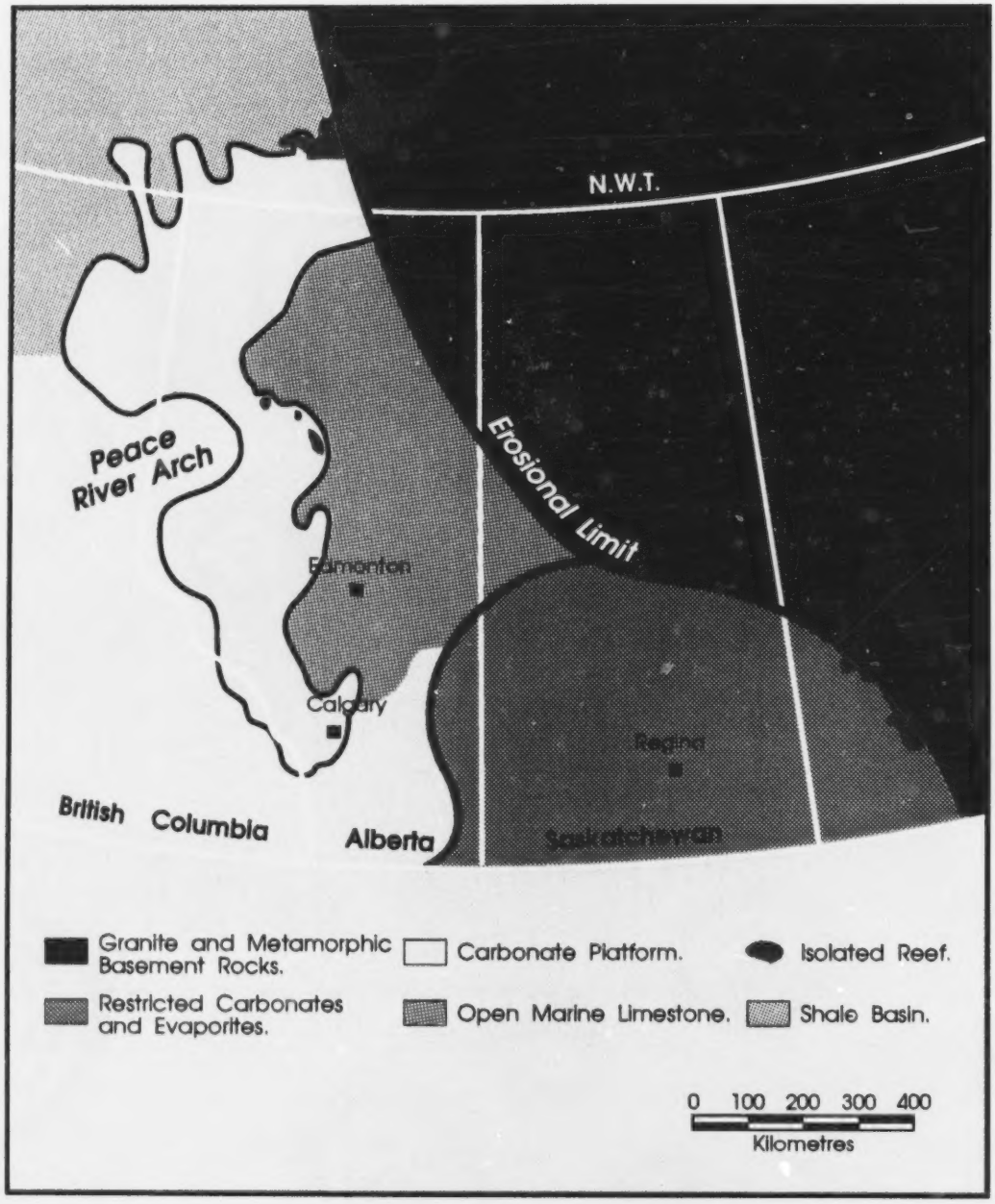
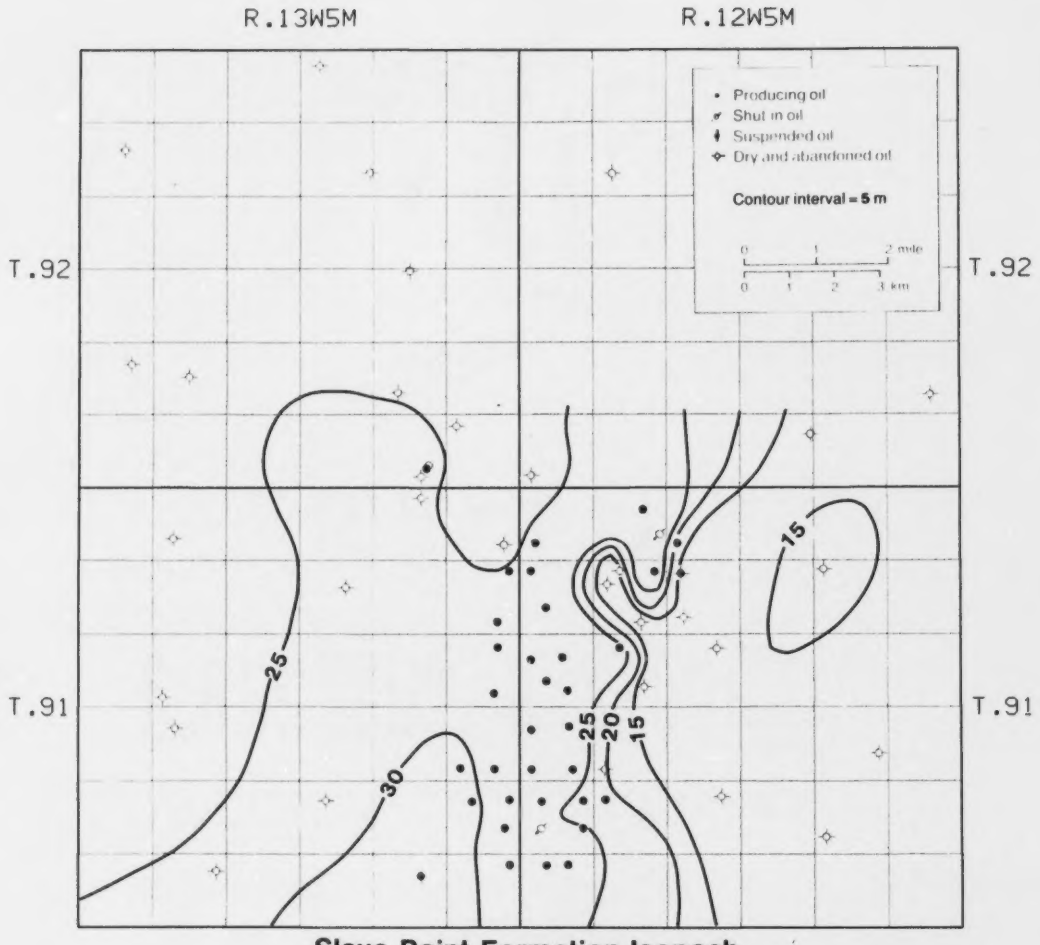


Figure 2.5 Paleogeography of the Middle Devonian Slave Point Formation (after Burrowes and Krause, 1987).

Figure 2.6

Isopach map of the Slave Point Formation. Note the abrupt thickening of the Slave Point Formation on the eastern edge of the field. Contour interval is 5 meters.



Slave Point Formation Isopach

Waterways formation unconformably overlies the Slave Point Formation (Featherstone, 1982; Norris and Uyeno, 1983; Park, 1984; Park and Jones, 1985). In the Hay River area, the Slave Point is disconformably overlain by the Waterways formation (Crawford, 1972; Hadley and Jones, 1990).

In northern and northeastern Alberta there is some brecciation in the Slave Point Formation (Norris 1963; Crawford, 1972; Norris and Uyeno, 1983; Park, 1984; Park and Jones, 1985). The absence of brecciation in the Slave Point Formation of the Peace River Arch area indicates that the Slave Point Formation sediments were probably not subaerially exposed. The top of the Slave Point Formation in this area is marked by a lithified, bored submarine-hardground. All evidence points to submarine conditions during hardground formation.

The age of the Slave Point Formation is difficult to determine because of the absence of datable fauna. For example, the brachiopods and corals in the Slave Point Formation are not diagnostic for age determination (Norris and Uyeno, 1983). However, ostracodes are present and have been used for correlation in the formation (Braun, 1968; Featherstone, 1982). Cameron (1918) assigned the formation to the Middle Devonian, though the fauna used are not diagnostic. The formation is generally regarded as Middle Devonian-Late Givetian in age (Braun, 1968; Norris and Uyeno, 1983).

In the Peace River Arch area only two studies have investigated the internal stratigraphy of the Slave Point Formation. The Slave Point Formation was informally divided in the Peace River Arch area into a "lower Slave Point reef" and an "upper Slave Point reef" (Podruski *et al.*, 1988). The basis for this division is not clear because

cross-sections were not presented with the study. Regional mapping of the Beaverhill Lake Group in north-central Alberta, investigated the correlation and relationship of depositional patterns to the Peace River Arch (Keith, 1990). Keith (1990) informally proposed that the Slave Point Formation carbonate buildups surrounding the Peace River Arch are stratigraphically equivalent to the Calumet member of the Waterways Formation. He suggested that these carbonate buildups are younger in age than the Slave Point Formation. Dating of these sediments was attempted, but, too few diagnostic microfauna were found in the samples (Keith, 1990). For the purposes of this study, the carbonate buildup at Sawn Lake field is referred to as the Slave Point Formation.

2.1.5 Swan Hills Formation

The Swan Hills Formation, southeast of the Peace River Arch, was originally designated the Slave Point Formation. The discovery of oil in the late 1950's led to its designation as the Swan Hills Member by Fong (1959). In the type section (10-10-67-10W5) the Swan Hills Member occurs at a depth of 2489 m to 2591 m and is characterized by both cryptocrystalline and granular limestone sequences which are dominated by stromatoporoids (Fong, 1959). Fischbuch (1968) proposed that the Swan Hills Formation is Givetian to Frasnian in age and correlated it with the upper part of the Slave Point Formation and the Waterways Formation.

2.1.6 Waterways Formation

The Waterways Formation was first proposed by Warren (1933) for a sequence of shale and argillaceous limestone alternating with mainly

limestone units exposed along the Athabasca River, near the town of Fort McMurray, in northeastern Alberta. Warren (1933) assigned a Late Devonian age to the formation. In the reference section (Bear Biltmore 7-11-87-17W4M), the Waterways Formation, at a depth of 299.0 to 512.8 m, was divided in ascending order into the Firebag, Calumet, Christina, Moberly, and Mildred members (Crickmay, 1957). All members of the Waterways Formation have characteristic lithologies described from the reference section.

The Waterways Formation was deposited during a transgression below fairweather wave base, in an open-marine setting. The sediment source for these interbedded limestones and shales was suggested to have originated from the eastern side of the basin (Sheasby, 1971). This formation downlaps onto the Slave Point Formation in the Peace River Arch area (Burrowes and Krause, 1987). The Waterways Formation overlies and is partly equivalent to the Swan Hills reef deposits in the Swan Hills area south and east of the Peace River Arch. The uppermost contact of the Waterways Formation is placed at the highest calcareous shale and shaly limestone which is overlain by the Cooking Lake Formation of the Woodbend Group (Norris, 1963).

2.1.7 Middle-Upper Devonian boundary

The Middle-Upper Devonian (Givetian-Frasnian) boundary had been placed in the lower part of the Calumet and Firebag members of the Waterways Formation (Norris and Uyeno, 1983). This boundary coincides with the *disparilis* conodont Zone at Gypsum Cliffs in northeastern Alberta. The subcommission on Devonian stratigraphy placed the Middle-Upper Devonian boundary at the lowermost boundary of the

Polygnathus asymmetricus conodont zone. This zone occurs approximately at the middle of the Calumet Member of the Waterways Formation (Ziegler and Klapper, 1985)

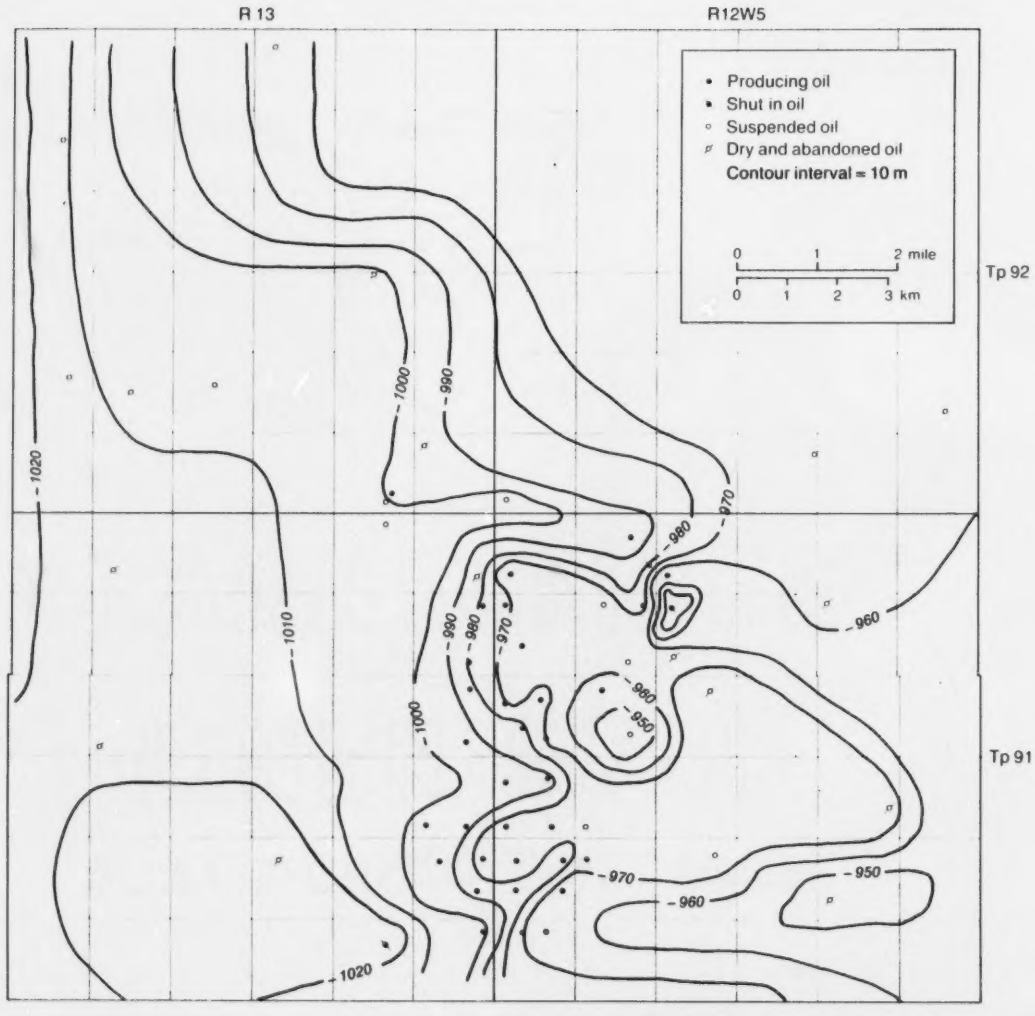
2.2 STRUCTURAL ATTITUDE OF THE SLAVE POINT FORMATION

The main structural components affecting the Slave Point Formation in the Sawn Lake area, are the regional dip and the structure on the Precambrian. The regional dip (approximately 6.3 metres/kilometer) to the southwest was superimposed on the Devonian during late and post-Paleozoic time. In the study area the maximum structure (20 m/km) on the Precambrian occurs along the eastern margin of the Sawn Lake field (Fig. 2.7). The Slave Point Formation at Sawn Lake field was deposited on a subtle topographic high on the pre-Slave Point Formation surface (Ferry, 1989). The Slave Point Formation carbonate buildups located directly south of Sawn Lake field, including Gift Lake (Davies and Tooth, 1987; Tooth and Davies, 1988), Slave (Dunham *et al.*, 1983), Golden-Evi (Gosselin, 1990) are also postulated to have developed on subtle paleotopographic highs originating at the Precambrian. The Sawn Lake field is located directly north of the Otter, Evi, and Gift Lake fields. This north-south alignment of Slave Point Formation fields indicates the approximate shelf-edge of the Slave Point Formation platform (Burrowes and Krause, 1987). The Slave Point Formation at Sawn Lake field has a wedge-shaped profile illustrated by abrupt thinning off the eastern edge and less abrupt thinning off the western edge of the field (Fig. 2.6).

The Beaverhill Lake Group is informally subdivided into a lower and upper package to illustrate the pattern of sediment infill east of the

Figure 2.7

Structural contours on the top of the Precambrian. Note the relative structural high on the eastern edge of the Sawn Lake field. The contour interval is 10 m and the datum is sea level.



Structural contours on top of the Precambrian

Peace River Arch. The isopach of the Fort Vermilion Formation to Waterways Formation Calumet Member, informally representing the lower portion of the Beaverhill Lake Group, suggests the absence of regional dip and influence of syndepositional basement tectonic activity (Fig. 2.8). The isopach of the Waterways Formation Christina Member to the top of the Beaverhill Lake group, informally representing the upper portion of the Beaverhill Lake Group, indicates a wedge-shaped profile from the northeast to southwest of about 0.6 m/km (Fig. 2.9). This uniform thinning of the upper members of the Waterways Formation towards the Arch is suggested to indicate the influence of regional dip and perhaps uniform basin subsidence during its deposition.

Figure 2.8

Isopach map of the top of the Calumet Member to the top of the Fort Vermilion Formation. Note the gradual thinning from the northeast to the southwest. Contour interval is 5 meters.

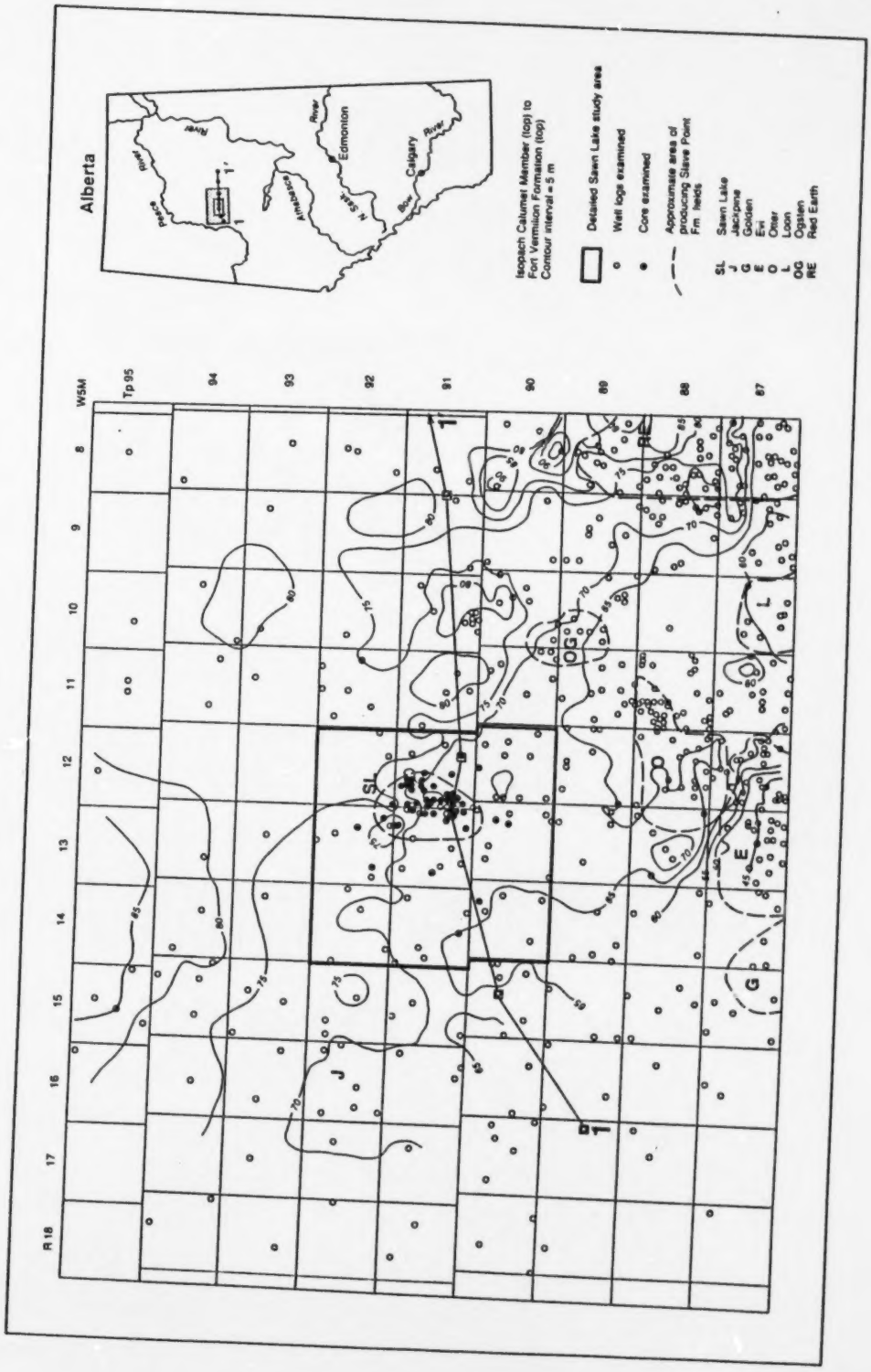
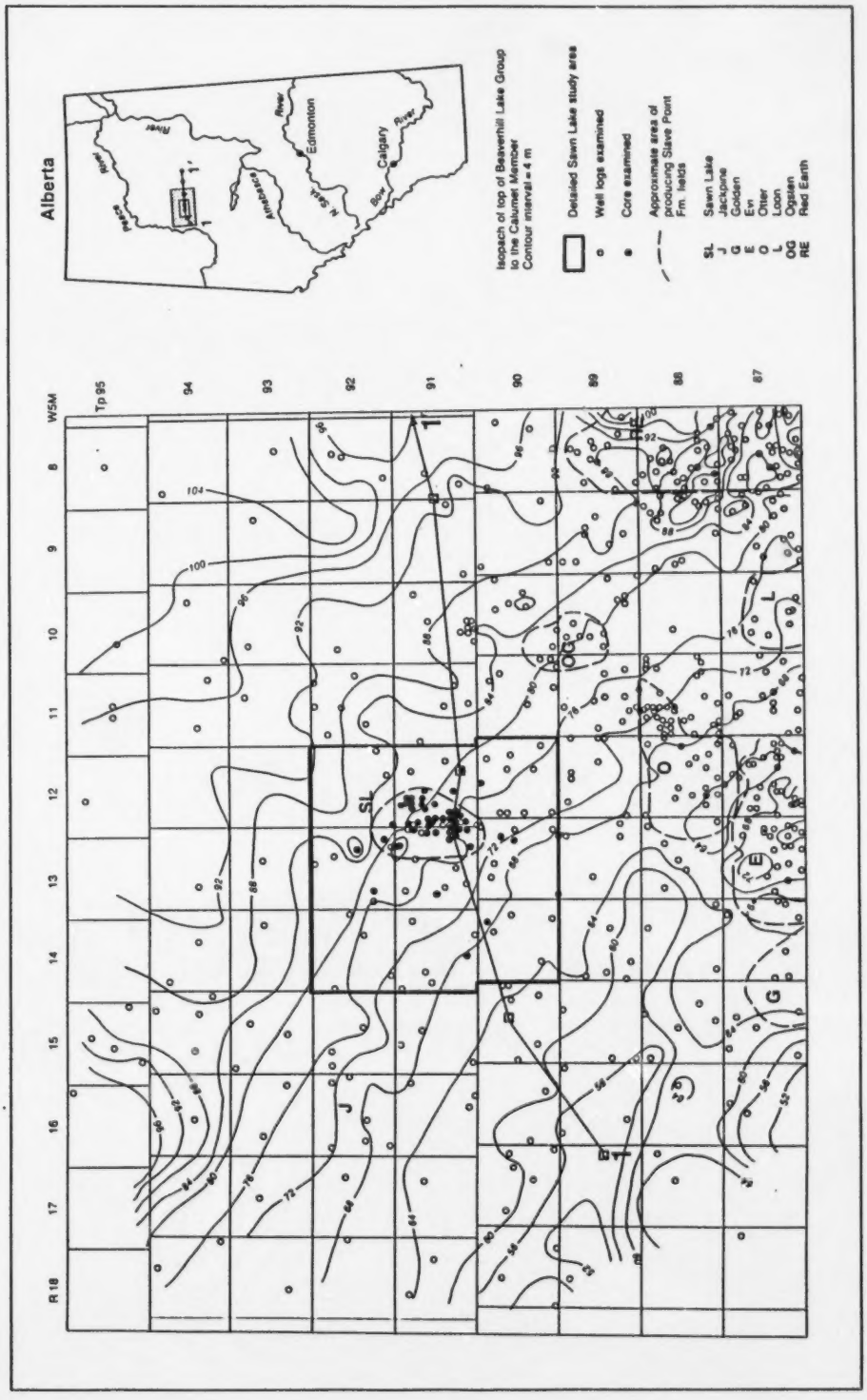

Alberta
Peace River
Athabasca River
N. Saskatchewan River
Edmonton
Bow River
Calgary
1
1'
Isopach Calumet Member (top) to Fort Vermilion Formation (top)
Contour interval = 5 m
Detailed Sawn Lake study area
Well logs examined
Core examined
Approximate area of producing Slave Point Fm fields
SL Sawn Lake
J Jacopine
G Golden
E Eri
O Otter
L Loon
OG Ogston
RE Red Earth
W5M
Tp 95
R 18
1
1'

Figure 2.9

Isopach map of the top of the Beaverhill Lake Group (top of the Mildred Member of the Waterways Formation) to the top of the Calumet Member of the Waterways Formation. Note the relatively constant thinning from the northeast to the southwest. Contour interval is 4 meters.


Alberta
Peace River
Athabasca River
N. Sask. River
Edmonton
Calgary
Bow River
Isopach of top of Beaverhill Lake Group to the Calumet Member
Contour interval = 4 m
Detailed Sawn Lake study area
Well logs examined
Core examined
Approximate area of producing Slave Point Fm. fields
SL Sawn Lake
J Jackpine
G Golden
E Evi
O Otter
L Loon
OG Ogston
RE Red Earth
Tp 95
94
93
92
91
90
89
88
87
W5M
8
9
10
11
12
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14
15
16
17
R 18
104
100
96
92
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84
80
76
72
68
64
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52

CHAPTER 3: FACIES DESCRIPTION

3.1 INTRODUCTION

A total of eleven facies (8 stratigraphically unconfined and 3 stratigraphically confined) were recognized from Slave Point Formation drill core. The facies are defined by the distinct association of fossil organisms and rock textures (Table 3.1). The facies are as follows:

Facies 1 Laminated limestone

Facies 2 Nodular limestone

Subfacies 2a Nodular mudstone

Subfacies 2b Nodular and wavy-bedded limestone

Facies 3 Nodular and bulbous stromatoporoid floatstone

Facies 4 Branching coral rudstone and floatstone

Facies 5 Cylindrical stromatoporoid rudstone and floatstone

Facies 6 Fenestral limestone

Facies 7 *Amphipora* limestone

Subfacies 7a Light-brown *Amphipora* floatstone and rudstone

Subfacies 7b Dark-brown *Amphipora* floatstone and rudstone

Facies 8 Subspherical stromatoporoid rudstone

Facies 9 Tabular stromatoporoid limestone

Subfacies 9a Wafer stromatoporoid floatstone and rudstone

Subfacies 9b Tabular stromatoporoid rudstone and bindstone

Facies 10 Fossiliferous packstone and grainstone

FACIES	DEPOSITIONAL TEXTURE	FAUNAL CONSTITUENTS	STRUCTURES	POROSITY	OTHER CONSTITUENTS
1 Laminated limestone	Mudstone to wackestone	*Tentaculites, Styliolina*	Planar/undulatory laminae	Intercrystalline (2 - 3 %)	Anhydrite and pyrite in lower decimeters
2a Nodular mudstone	Mudstone to wackestone	As above	Densly-packed, ovoid to elongate nodules (0.5-4 cm diam)	Intercrystalline (2 - 4 %)	Nodules contain peloids *Tentaculites, Styliolina* and algae
2b Nodular and wavy-bedded limestone	Mudstone to wackestone, some packstone	Common *Amphipora* brachiopods,crinoids, tabular stromatoporoids	Ovoid to elongate matrix-supported nodules (0.5-4 cm diam)	Intercrystalline (2 - 4 %) and microporosity	Nodules contain peloids, branching corals and cylindrical stromatoporoid fragments. Crinoids in nodules and matrix
3 Nodular and bulbous stromatoporoid floatstone	Minor peloidal and skeletal packstone	Abundant nodular and bulbous stromatoporoids and oncoids	Mottled texture and low-amplitude stylolites	Intergranular (3 - 5 %)	Sparse nodular stromatoporoids, branching corals, *Amphipora*
4 Branching coral rudstone and floatstone	Wackestone and packstone	Abundant branching corals and common cylindrical stromatoporoids	Mottled texture with pyritized hardground surfaces	Intergranular (3 - 6 %)	Sparse brachiopods
5 Cylindrical stromatoporoid rudstone and floatstone	Wackestone, packstone and minor grainstone	Abundant cylindrical stromatoporoids and common branching corals	Low-amplitude stylolites	Intergranular (4 - 9 %)	Sparse crinoids and brachiopods
6 Fenestral limestone	Mudstone, wackestone, packstone and minor grainstone		Fenestrae, mottled texture and algal laminations	Intergranular and intercrystalline (2 - 4 %)	Sparse *Amphipora* gastropods and ostracods
7a Light-brown *Amphipora* floatstone and rudstone	Wackestone to peloidal packstone and grainstone	Abundant *Amphipora* (2-4 mm diameter)	Parallel stratification and low-amplitude stylolites	Intergranular (3 - 6 %)	
7b Dark-brown *Amphipora* floatstone and rudstone	Mudstone to wackestone	Abundant *Amphipora* (2-4 mm diameter), frequently abraded	Low-amplitude stylolites	Intergranular (3 - 5 %)	Sparse bored and encrusted nodular and bulbous and cylindrical stromatoporoids

Table 3.1 Facies of the Slave Point Formation.

FACIES	DEPOSTIONAL TEXTURE	FAUNAL CONSTITUENTS	STRUCTURES	POROSITY	OTHER CONSTITUENTS
8 Subspherical stromatoporoid rudstone	Mudstone, wackestone, packstone and grainstone	Abundant bulbous, hemispherical and massive stromatoporoids	Low- and high-amplitude stylolites	Intergranular and intercrystalline (3 - 8 %)	Abraded subspherical, irregular cylindrical stromatoporoids *Amphipora* and branching coral
9a Wafer stromatoporoid floatstone and rudstone	Bituminous mudstone and wackestone	Abundant wafer stromatoporoid (0.5-1 cm thick), commonly abraded and fractured	Irregular stylolites	Intergranular (4 - 5 %)	Common to sparse brachiopods, cylindrical stromatoporoids, branching and rugose corals, crinoids
9b Tabular stromatoporoid rudstone and bindstone	Skeletal packstone and grainstone	Abundant tabular stromatoporoids	Nodular and mottled fabrics. Microstylolite swarms.	Intergranular, shelter cavity and moldic (4 -9 %, max 15%)	Common to sparse irregular, encrusting subspherical stromatoporoids, crinoids, brachiopods, cylindrical stromatoporoids
10 Fossiliferous grainstone and packstone	Skeletal packstone and grainstone	Abundant to common crinoids and brachiopods		Intergranular (4 - 10 %)	Common to sparse branching corals, gastropods, bulbous and cylindrical stromatoporoids.
11 Massive lime mudstone	Argillaceous and carbonaceous mudstone	Common calcispheres *Tentaculites, Styliolina*	Parallel stratification	Intercrystalline (2 - 3 %)	Sparse abraded and fragmental branching corals, brachiopods, cylindrical stromatoporoids.

Table 3.1**(continued)** Facies of the Slave Point Formation.

Facies 11 Massive lime mudstone

3.2 FACIES DESCRIPTION

3.2.1 Facies 1: Laminated Limestone

Facies 1 consists of thin mudstone to wackestone beds (0.5 mm to 3 cm) separated by planar to undulatory laminae and stylolites (0.5 to 5 mm thick) (Fig. 3.1). The laminated limestones locally contain biogenically reworked sediment, subrounded oncoids, and rare brachiopods, ostracods and crinoids.

3.2.2 Facies 2: Nodular Limestone

Facies 2 consists of light-coloured limestone nodules surrounded by darker-coloured carbonaceous laminae, and stylolites in a mudstone to wackestone matrix. Two distinct variations of Facies 2, Subfacies 2a and 2b, are defined by nodule shape and density. The nodular mudstones (Subfacies 2a) consist of dark grey to brown, closely packed nodules separated by carbonaceous laminae and stylolites (Fig. 3.2a). The nodular and wavy-bedded limestones (Subfacies 2b) consist of medium to dark brown lime mudstones to skeletal wackestones and packstones (Fig. 3.2b, 3.2c). The wavy-bedding of Subfacies 2b consists of nodules surrounded by various amounts of thick, continuous laminae to thin beds of argillaceous material.

3.2.3 Facies 3: Nodular and Bulbous Stromatoporoid Floatstone

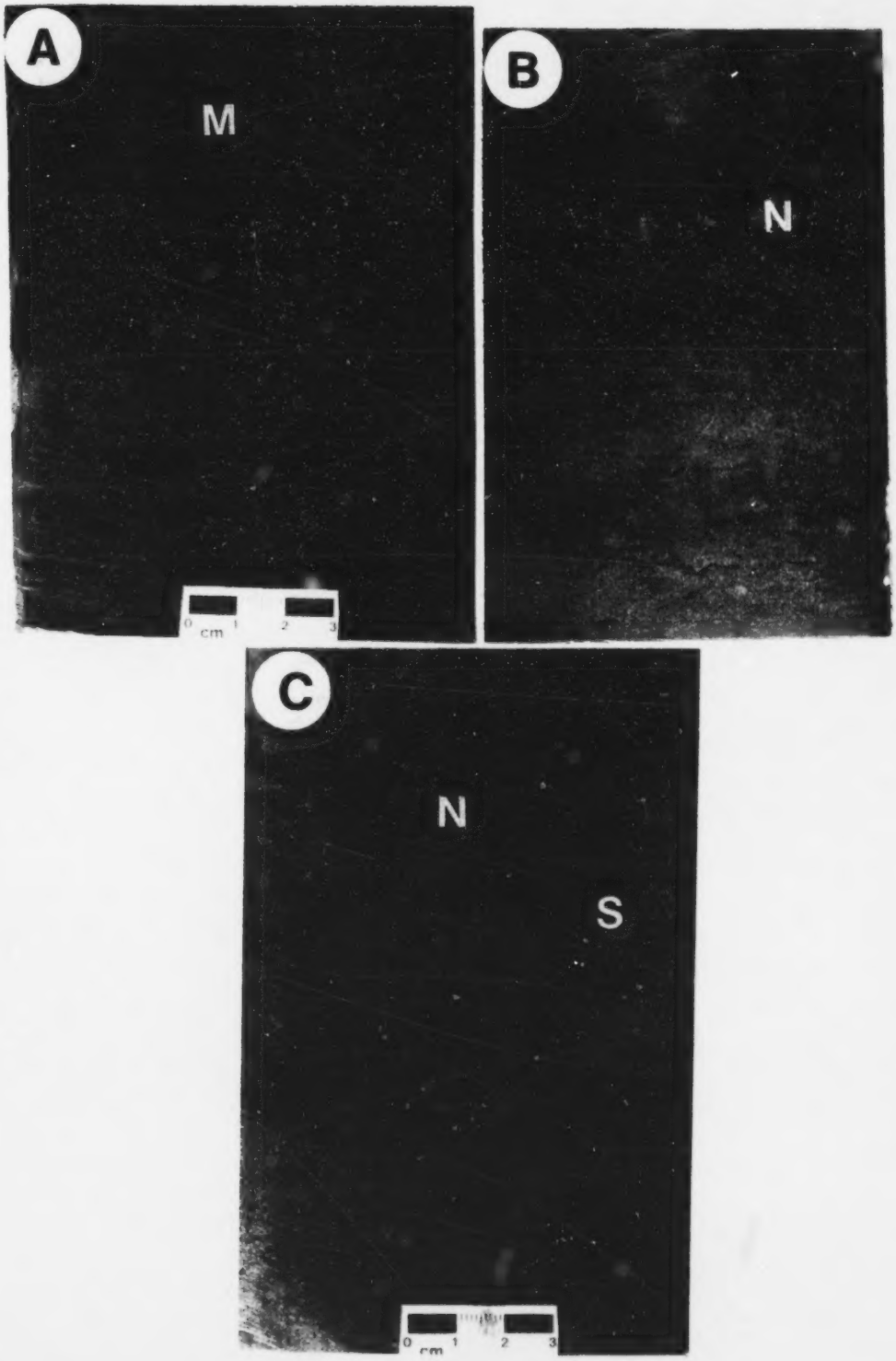
Facies 3 consists of abundant nodular and bulbous stromatoporoid floatstones and minor rudstones in a bituminous, medium-grained, peloidal and skeletal packstone matrix (Fig. 3.3). Typically,

Figure 3.1 - Facies 1

a) Laminite (Facies 1) consisting of wackestone to packstone laminae and thin beds separated by millimeter argillaceous partings and microstylolites (M). The photograph is from 15-21-91-12W5, 1607 m. Scale bar gradations are in centimeters (cm).

b) Laminite (Facies 1) consisting of discontinous stylolites and nodules (N) in a wackestone matrix. The photograph is from 15-21-91-12W5, 1603 m. Core width is 8 cm.

c) Laminite (Facies 1) consisting of faint nodules (N) and discontinuous stylolites. The photograph is from 4-11-91-12W5, 1615.4 m. Scale bar gradations are in cm.


A
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B
N
C
N
S
0 cm 1 2 3
0 cm 1 2 3

Figure 3.2 - Facies 2

a) Nodular mudstone (Subfacies 2a) consisting of densely packed mudstone nodules separated by stylolites. The photograph is from Scale bar gradations are in cm. The photograph is from 4-31-91-12W5, 1625 m. Scale bar gradations are in cm.

b) Nodular to wavy-bedded limestone (Subfacies 2b) consisting of mudstone to wackestone nodules (N) separated by argillaceous partings and stylolites. Nodules contain abraded branching corals and *Amphipora* (arrow). The photograph is from 15-24-91-13W5, 1577.86 m. Scale bar gradations are in cm.

c) Dark brown bituminous and argillaceous nodular mudstone (Subfacies 2b). Spherical nodule appears burrowed (B). Elongate nodule (N) contains rare gastropod. The photograph is from 15-9-91-12W5, 1609.2 m. Core width is 8 cm.

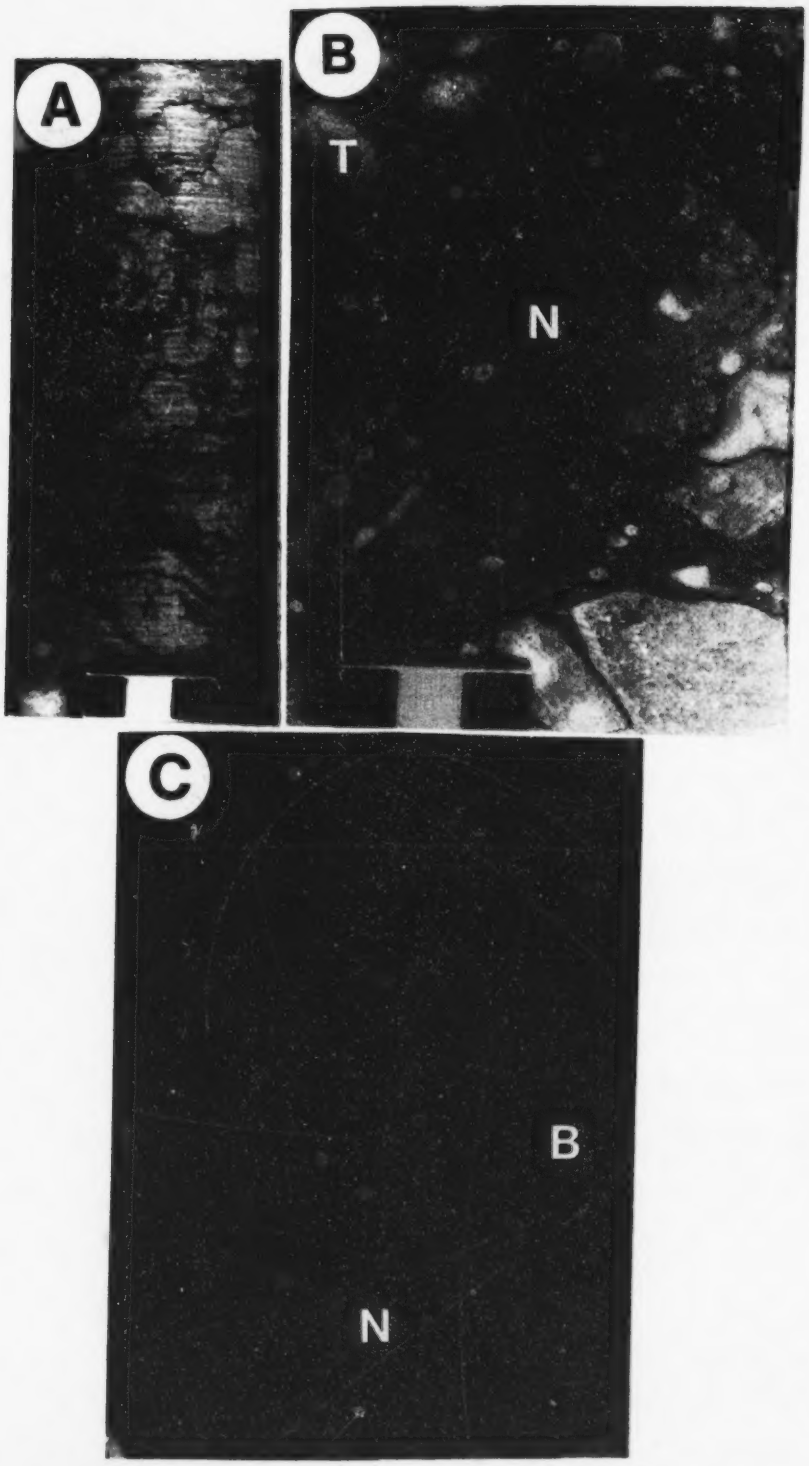
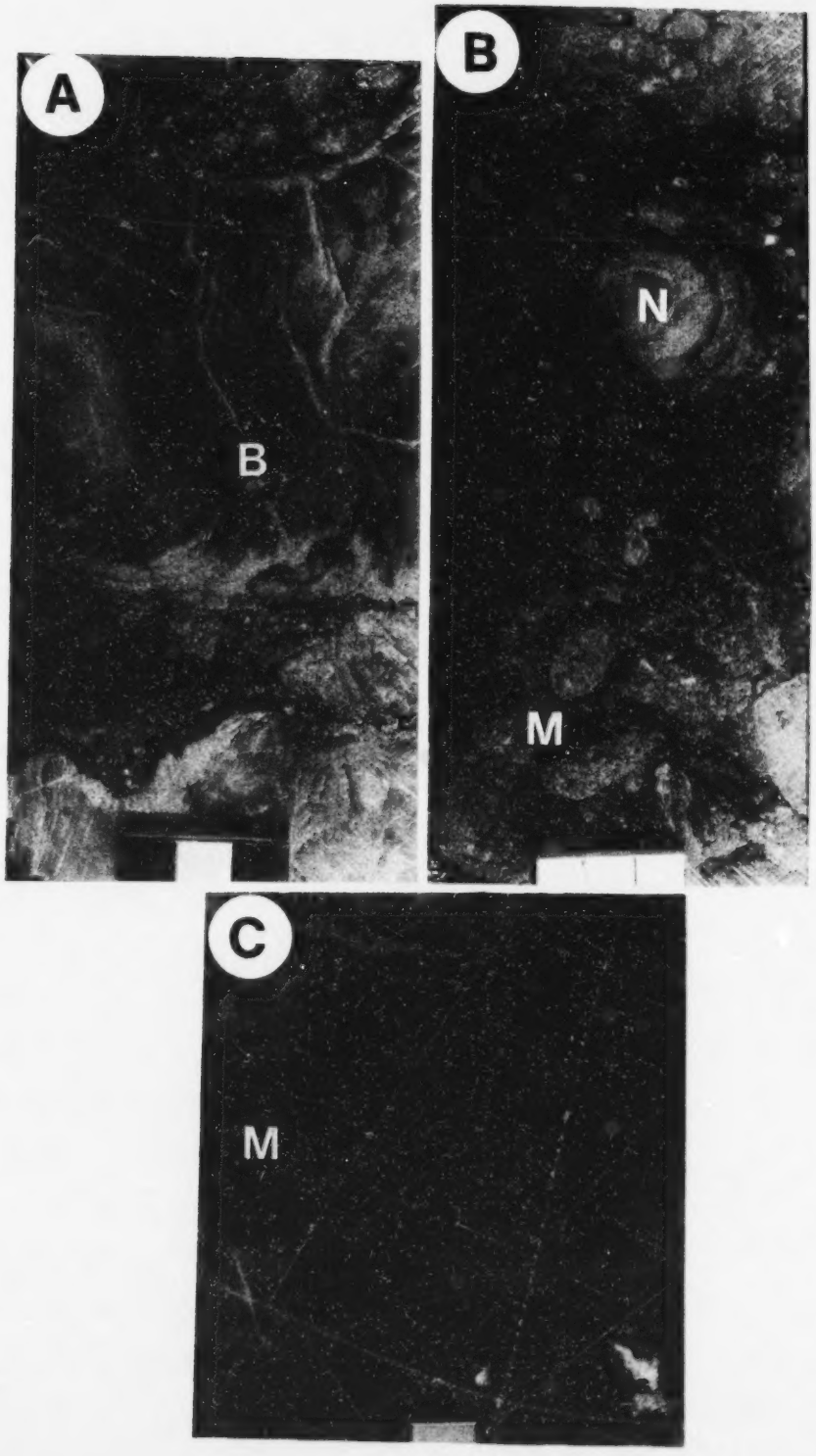

A
B
T
N
C
B
N

Figure 3.3 - Facies 3

a) Nodular and bulbous stromatoporoid floatstone (Facies 3) consisting of hemispherical stromatoporoid with sponge borings (B) geopetally filled with calcite spar and micrite in a packstone to grainstone. Subordinate fauna include stromatoporid fragments and cylindrical stromatoporoids. The photo is from 15-35-91-13W5, 1644.2 m. Scale bar gradations are in cm.

b) Nodular and bulbous stromatoporoid floatstone (Facies 3) consisting of encrusted nodular (N) stromatoporoid in a stylotized and mottled (M) packstone. The photo is from 15-24-91-13W5, 1577.1 m. Scale bar gradations are in cm.

c) Sponge boring (M) filled with micrite and calcite spar in a mottled and microstylotized wackestone. Fractures and voids filled with calcite spar (s). The photo is from 15-24-91-13W5, 1577.4 m. Scale bar gradations are in cm.


A
B
B
N
M
C
M

Trypanites and sponge borings penetrate the nodular and bulbous stromatoporoids. The irregularly-spaced, micrite-filled *Trypanites* are less than 2 mm in diameter, elongate, and circular in cross-section (Fig. 3.3a). The sponge borings consist of a single rounded chamber (0.5 to 3.0 cm in diameter) with one or more straight tubular canals (0.1 to 0.3 cm thick and 0.5 to 2.5 cm long) radiating outwards from the large chamber (Fig. 3.3a, 3.3c). The central chamber is filled geopetally with dark-coloured micrite, overlain by sparry calcite (Fig. 3.3c). These geopetal fabrics indicate the orientation of the stromatoporoid head at the time the fill was emplaced. These sponge borings are similar to *Uniglobites*, identified in corals, bivalves and gastropods of the Oligocene-Miocene Bluff Formation of Grand Cayman Island (Pleydell and Jones, 1988). They have also been identified from other Devonian stromatoporoids as borings of the ichnogenus *Topsentopsis*, constructed by the activity of macro-endolithic coelobionts and thought to be sponges (Gosselin and Smith, 1987b).

3.2.4 Facies 4: Branching Coral Rudstone and Floatstone

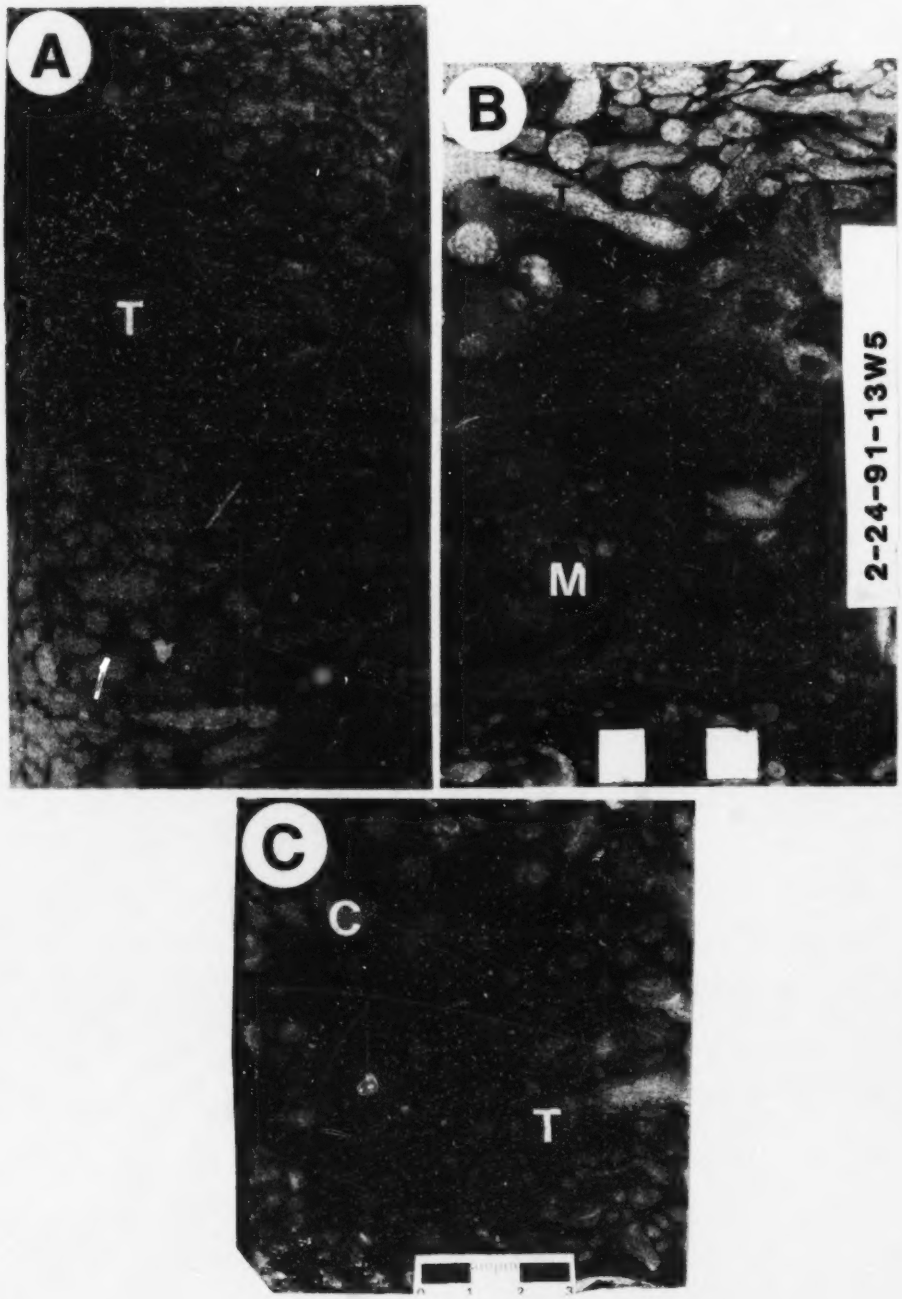
Facies 4 consists of common to abundant branching corals in dark-brown to medium-grey wackestones and packstones (Fig. 3.4). Abraded cylindrical stromatoporoids and patches of mottled texture are locally developed in the floatstones (Fig. 3.4c). The floatstones are typically highly bituminous. One to three stacked planar hardgrounds occur in the lower part of the facies.

Figure 3.4 - Facies 4

a) Branching coral (T) rudstone in a wackestone to packstone matrix. Coral contacts are commonly stylotized. The photo is from 9-7-91-12W5, 1618.4 m. Core width is 8 cm.

b) Basal portion of branching coral packstone (Facies 4) consisting of mottled (M) texture and skeletal fragments grading upwards with branching corals in a bituminous and stylotized matrix. The photo is from 2-24-91-13W5, 1578.8 m. Scale bar gradations are in cm.

c) Branching coral skeletal packstone (Facies 4) consisting of fragmented branching corals (T) and cylindrical stromatoporoids (C). Dark brown areas of matrix are microstylotized and bituminous. The photo is from 11-12-91-13W5, 1632.3 m. Scale bar gradations are in cm.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2-24-91-13W5
C
C
T

3.2.5 Facies 5: Cylindrical Stromatoporoid Rudstone and Floatstone

Facies 5 is characterized by common to abundant cylindrical stromatoporoids in a matrix that varies from dark carbonaceous wackestones to packstones and minor grainstones (Fig. 3.5). Typically, cylindrical stromatoporoids are abraded and smaller in size in the wackestones (Fig. 3.5b) and larger in size in the packstones and grainstones (Fig. 3.5a, 3.5c).

Pyritized, low-relief hardgrounds (less than 2 cm) commonly occur at the basal contact of the facies. *Trypanites*, commonly penetrate the surface of the hardground, in addition to unidentified vertical v-shaped borings (1 to 3 cm in length).

3.2.6 Facies 6 - Fenestral Limestone

Facies 6 is characterized by fenestral lime mudstones, peloid-intraclast packstones to wackestones and minor skeletal grainstones. Laminoid, irregular and tubular fenestral fabrics occur in this facies. These fabric types are defined after the terminology of Read (1973). The laminoid fenestral fabric consists of horizontally elongate fenestrae (1 to 3 mm thick, 1 to 2 cm in length) interbedded with millimetre, partially laminated layers of limestone (Fig. 3.6a). The irregular fenestral fabric consists of irregular to spherically-shaped fenestrae (1 to 4 mm thick) interbedded with laminated layers of limestone (Fig. 3.6b). The less common tubular fenestral fabric, consists of straight to cylindrical and curved fenestrae (1 to 3 mm thick) scattered irregularly in the sediment (Fig. 3.6c).

The fenestral limestones contain algal-laminations which are commonly crinkled, with 1 to 3 mm thick layers of grains separated by

Figure 3.5 - Facies 5

a) Cylindrical stromatoporoid skeletal packstone floatstone (Facies 5). Cylindrical stromatoporoids (C) are dominant with brachiopods (B) and crinoids scattered throughout. The photo is from 8-7-91-12W5, 1639.6 m. Scale bar gradations are in cm.

b) Abraded and fragmented cylindrical stromatoporoids (C) and branching corals (T) in a cylindrical stromatoporoid dark grey wackestone (Facies 5). The photo is taken from 2-24-91-13W5, 1578.4 m. Scale bar gradations are in cm.

c) Cylindrical stromatoporoid grainstone (Facies 5). The rudstone consists of abraded stromatoporoids (C) with stylotized contacts (arrow). The photo is from 8-7-91-12W5, 1635.7 m. Scale bar gradations are in cm.

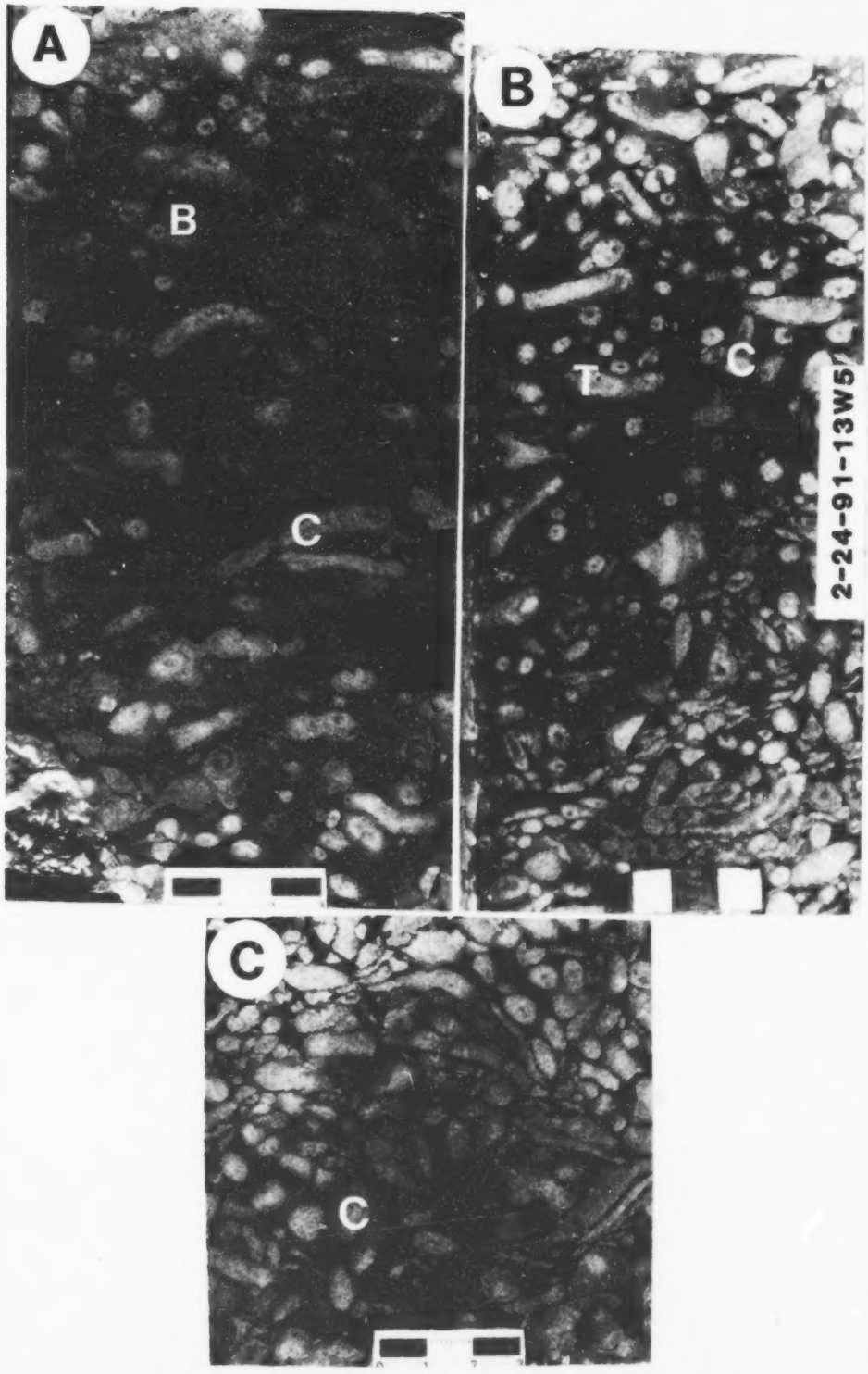

A
B
C
B
T
C
2-24-91-13W5
C
C

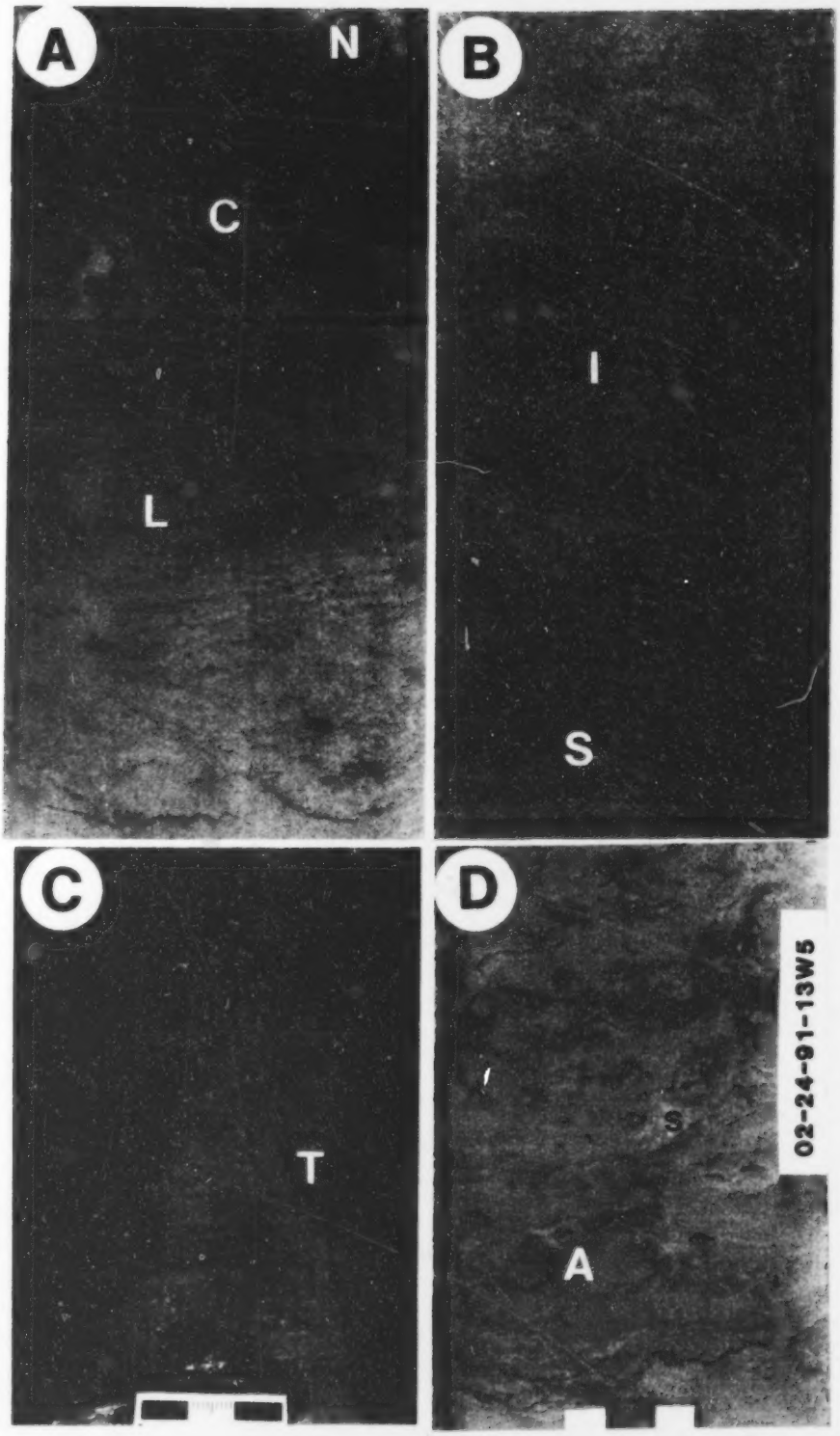
Figure 3.6 - Facies 6

a) Fenestral limestone (Facies 6) consisting of laminoid fenestrae (L) and some irregular fenestrae above. Large voids are filled with calcite spar (S). Fenestral limestones are sharply overlain (C) by dark brown amphiporid limestone (Subfacies 7b) containing nodular stromatoporoids (N). The photo is from 15-24-91-13W5, 1571.3 m. Core width is 8 cm.

b) Fenestral limestone (Facies 6) consisting of irregular fenestrae (I) and faint lamination. Irregular stylolite (S) parallel to stratification. The photo is from 15-24-91-13W5, 1572.2 m. Core width is 8 cm.

c) Fenestral limestone (Facies 6) consisting of tubular fenestrae (T) and irregular fenestrae. Fenestrae varies from a dense to sparse packing pattern. The photo is from 11-12-91-13W5, 1626.1 m. Scale bar gradations are in cm.

d) Algal laminations (A) containing an irregular pattern of blue-grey mottling. Large voids filled with calcite spar (S). The photo is from 2-24-91-13W5, 1572.8 m. Scale bar gradations are in cm.


A
N
C
L
B
I
S
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S
A
02-24-91-13W5

irregular layers of millimeter scale carbonate sediment and sparry calcite (Fig. 3.6d). The algal-laminated structures are comprised of laminae alternating between light-brown to dark-brown bands of color. Light-brown nodules, partially coloured blue-grey, distinguished by the colour contrast with a darker brown matrix, occur in the algal-laminated portions of Facies 6 (Fig. 3.6d).

3.2.7 Facies 7 - *Amphipora* Limestone

Amphipora limestones consist of two intergradational types, Subfacies 7a (light-brown *Amphipora* floatstones and rudstones) and Facies 7b (dark-brown *Amphipora* floatstones and rudstones), primarily distinguished by the grain size of the matrices. Subfacies 7a has a light-brown wackestone to peloidal packstone and grainstone matrix (Fig. 3.7a, 3.7b, 3.7c and Fig. 3.8a). Subfacies 7b has a medium- to dark-brown mudstone to wackestone matrix (Fig. 3.8b). *Amphipora* are sparse to abundant in this facies.

3.2.8 Facies 8 - Subspherical Stromatoporoid Rudstone

Facies 8 is characterized by subspherical stromatoporoids in a matrix which varies from mudstones and wackestones to packstones and minor skeletal, peloidal grainstones (Fig. 3.9). Subspherical stromatoporoids consist of nodular, bulbous, hemispherical and massive forms.

3.2.9 Facies 9 - Tabular Stromatoporoid Floatstones and Bindstone

Facies 9 is characterized by tabular stromatoporoids in a matrix which varies from mudstones and wackestones to skeletal-packstones and

Figure 3.7 - Facies 7

a) Light brown amphiporid limestone (Subfacies 7a) consisting of beds (0.5 to 2.0 cm) alternating between light-coloured rudstones (A) and dark brown bituminous less densely packed rudstones. Stromatoporoid fragments are encrusted (E). The photo is from 2-24-91-13W5, 1571.4 m. Scale bar gradations are in cm.

b) Dark brown amphiporid limestone (Subfacies 7b) consisting of beds of dark brown bituminous *Amphipora* (A) with stylotized contacts alternating with wackestone to packstone beds devoid of *Amphipora*. Bulbous stromatoporoid (B) is compacted onto amphiporid bed. The photo is from 11-12-91-13W5, 1626.4 m. Scale bar gradations are in cm.

c) Light brown amphiporid limestone (Subfacies 7a) consisting of irregular stromatoporids (I) in a floatstone packstone to grainstone matrix. The photo is from 11-12-91-13W5, 1631.1 m. Scale bar gradations are in cm.

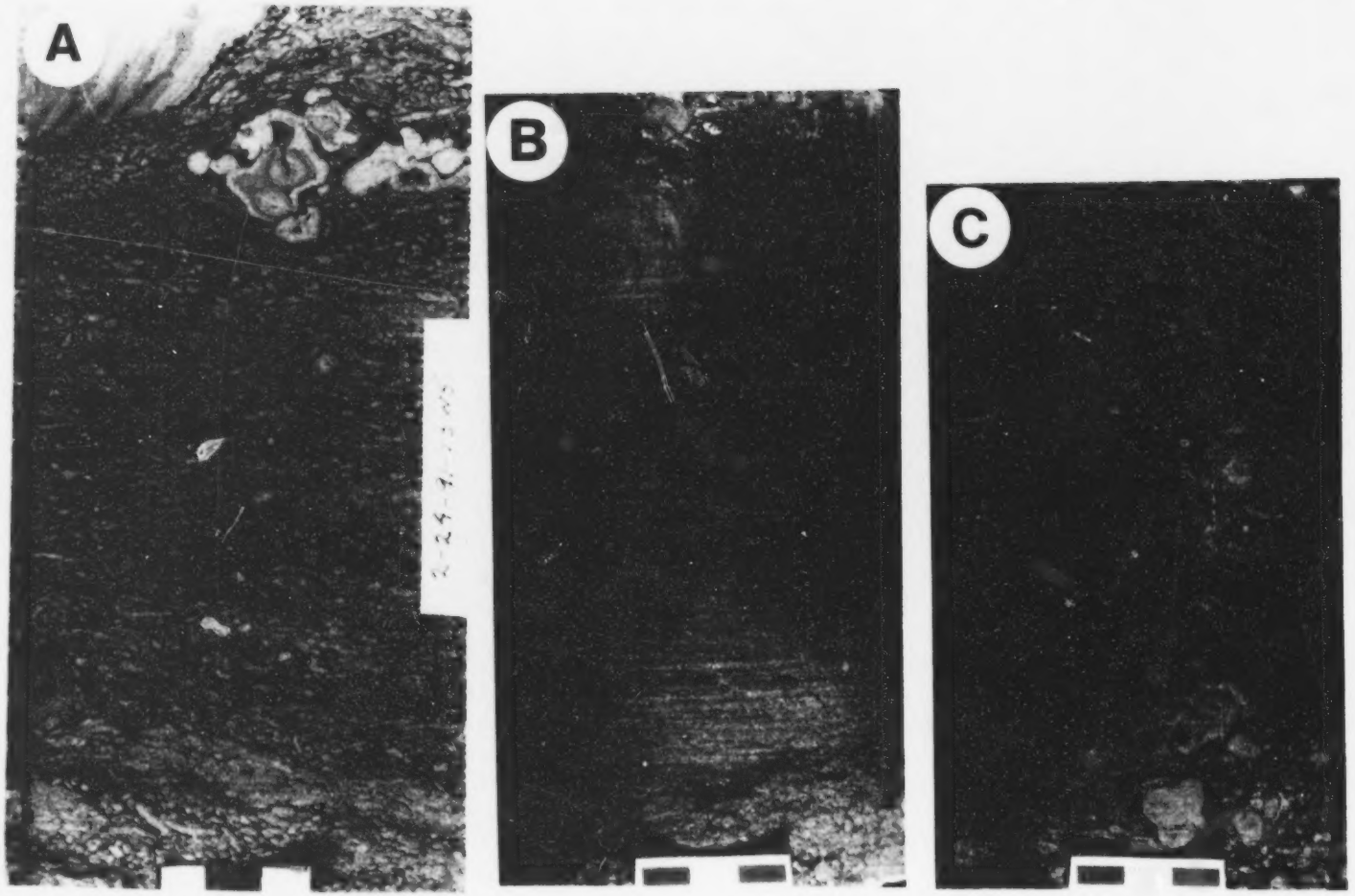

A
B
C

Figure 3.8 - Facies 7

a) Light brown amphiporid limestone (Subfacies 7a) consisting of shelter cavity porosity filled with calcite spar (S). The robust *Amphipora* (A) are densely packed in a matrix which consists of fine grained skeletal material and coated grains. The photo is from 9-12-91-13W5, 1613.0 m. Scale bar gradations are in cm.

b) Dark brown amphiporid limestone (Subfacies 7b) consisting of less robust *Amphipora* (A) in a rudstone to floatstone. The dark brown mudstone matrix is bituminous and contains stylolitization. The photo is from 8-7-91-12W5, 1634.3 m. Scale bar gradations are in cm.

c) Photomicrograph from a thin section taken from fig. 3.8 a. Note the galleries of the *Amphipora* (A) and shelter cavity porosity are both filled with calcite spar (S). The matrix consists of fine-grained skeletal material and coated grains. The photomicrograph is from 9-12-91-13W5, 1613.0 m. Width of photo is 2.6 cm.

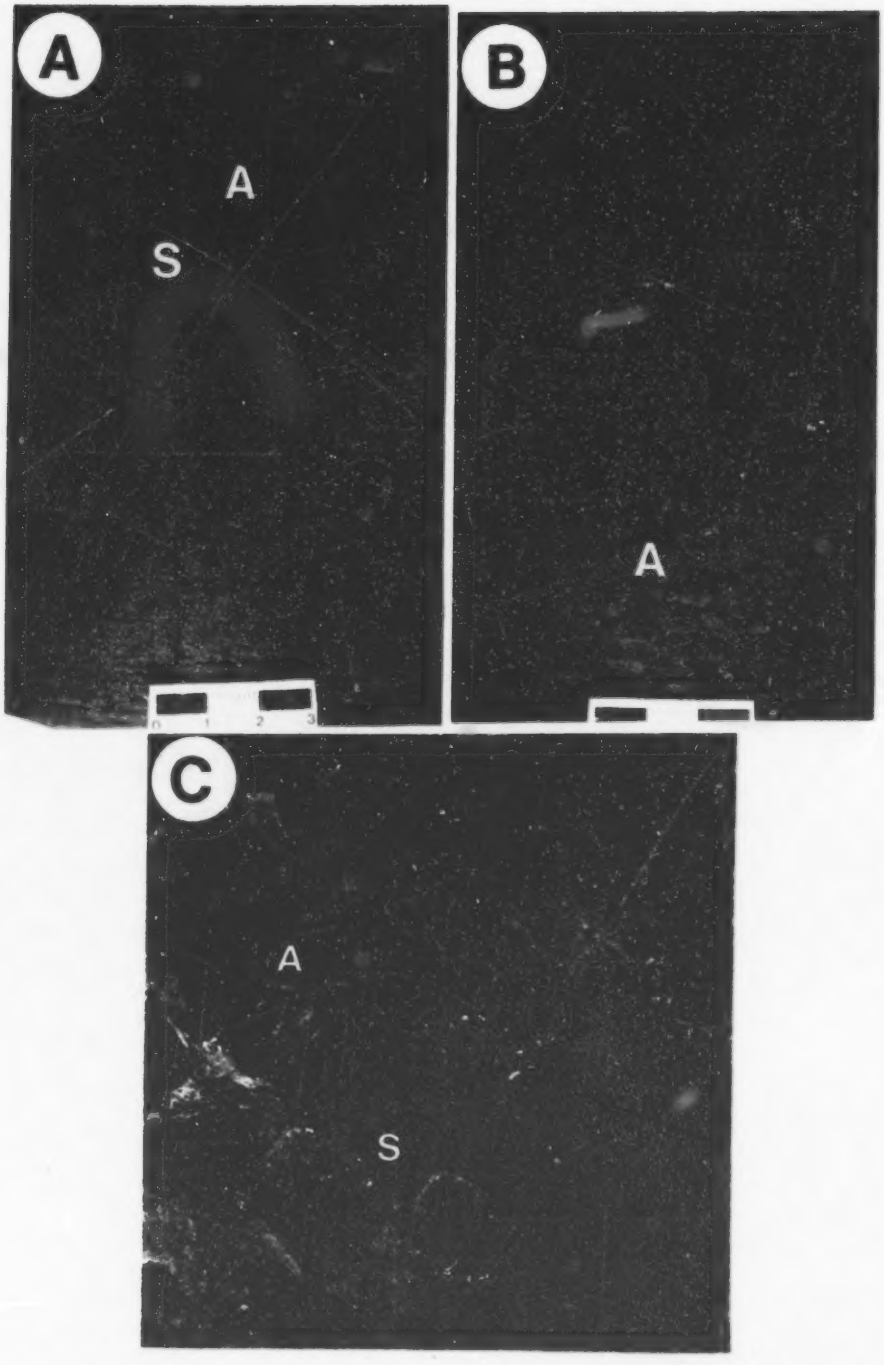

A
A
S
B
A
C
A
S

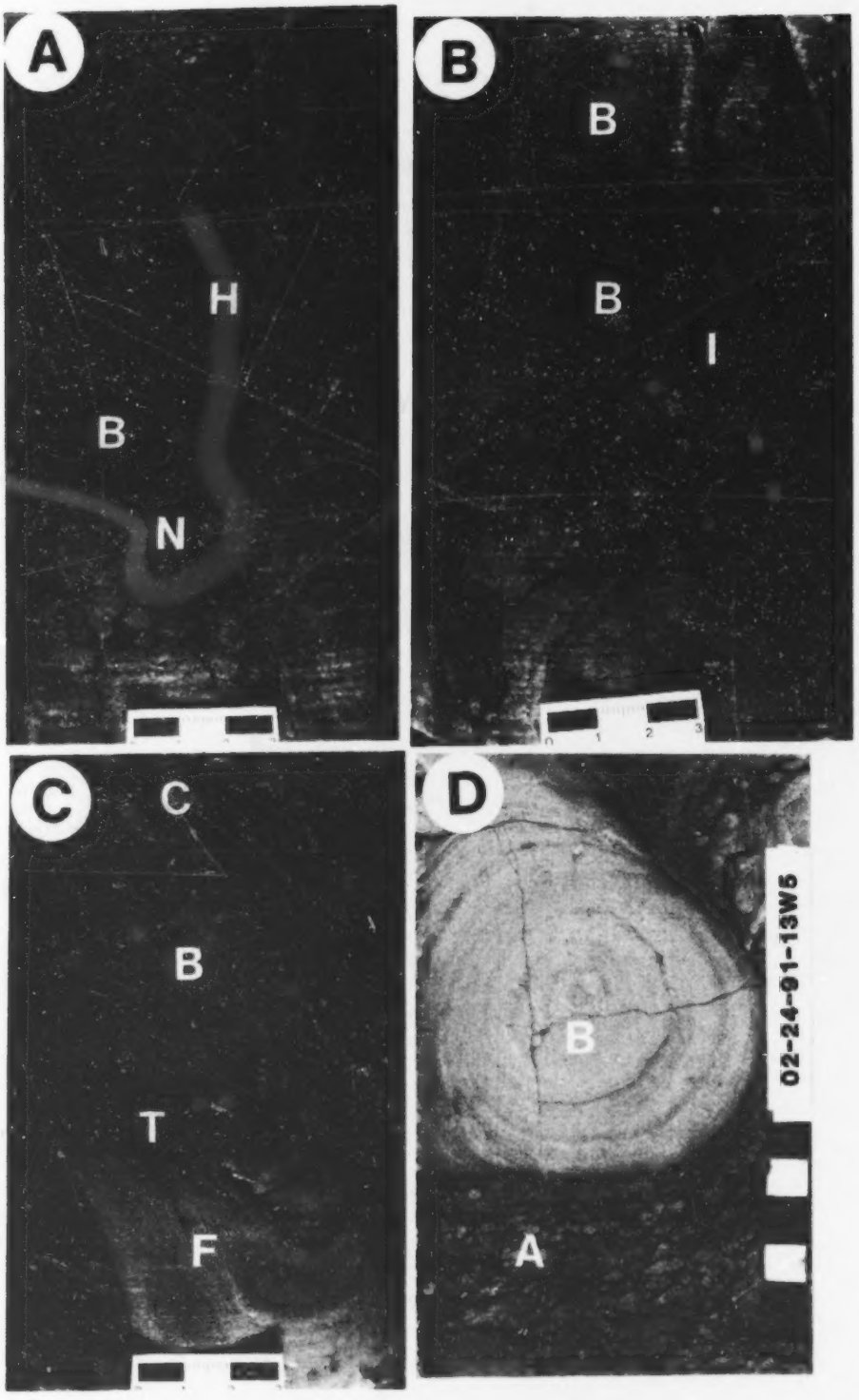
Figure 3.9 - Facies 8

a) Subspherical stromatoporoid rudstone (Facies 8) consisting of nodular (N), bulbous (B) and hemispherical (H) stromatoporoids having stylotized contacts (arrow). The bituminous skeletal wackestone to packstone contains fragmented stromatoporoids. The photo is from 9-12-91-13W5, 1611.4 m. All scale bar gradations for figure 3.9 are in cm.

b) Subspherical stromatoporoid floatstone (Facies 8) consisting of bulbous (B) and irregular (I) stromatoporoids in a dark brown bituminous mudstone matrix with stylotized stromatoporoid contacts. The photo is from 8-7-91-12W5, 1634.3 m.

c) Subspherical stromatoporoid floatstone (Facies 8) consisting of bulbous (B) stromatoporoids and abraded portions (F) of irregular and spherical stromatoporoids. The dark brown bituminous wackestone contains subordinate fragmented branching corals (T) and cylindrical stromatoporoids (C). The photo is from 11-12-91-13W5, 1632.8 m.

d) *Amphipora* (A) and bulbous stromatoporoids (B) in a peloidal and skeletal packstone comprise this subspherical stromatoporoid floatstone (Facies 8). Irregular stylolites occur where *Amphipora* are present.


A
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B
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02-24-01-13W5

minor peloidal grainstones (Fig. 3.10). Two intergradational variations of this facies, include (1) Subfacies 9a characterized primarily by wafer stromatoporoid (0.5 to 1 cm thick) floatstones (Fig. 3.10a, 3.10c); and (2) Subfacies 9b characterized primarily by thick tabular stromatoporoid (greater than 1 cm thick) bindstones (Fig. 3.10b, 3.10d). The tabular stromatoporoids in Subfacies 9b encrust and incorporate irregular and subspherical stromatoporoids (Fig. 3.10b).

3.2.10 Facies 10: Fossiliferous Packstones and Grainstone

The fossiliferous packstones and grainstones are characterized by light brown, medium- to coarse-grained allochems (Fig. 3.11). The allochems, consisting primarily of stromatoporoid fragments, are subrounded to moderately well-rounded and vary in size from 0.2 to 0.5 mm. The texture of Facies 10 is variable, but generally moderately well-sorted and commonly homogenized by biogenic reworking. The grainstones commonly consist of abundant crinoids and brachiopods.

3.2.11 Facies 11: Massive Lime Mudstone

This facies is characterized by medium-brown to dark-brown and occasionally black, massive lime mudstones (Fig. 3.12). The term massive is used here to indicate a thick, homogenous bed that appears to be without internal structure. The carbonaceous content in this facies can vary in the same core from very high to low and is reflected by the contrast in colour from dark-brown to medium brown.

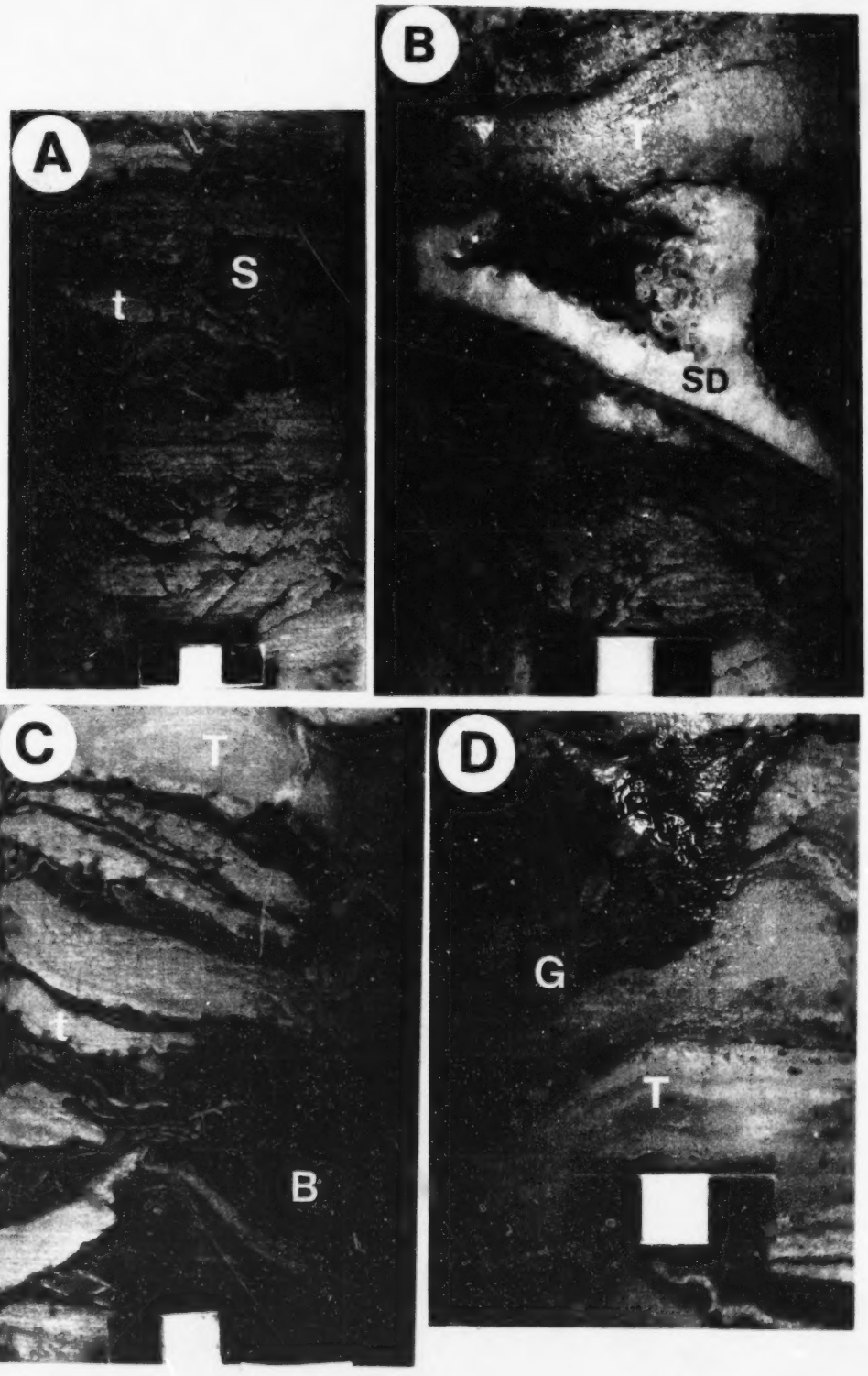
Figure 3.10 - Facies 9

a) Wafer (t) and tabular stromatoporoid rudstone (Subfacies 9a) consisting of a dark brown bituminous skeletal wackestone. Note the irregular stylolites (S) separating the stromatoporoids. The photo is from 8-7-91-12W5, 1630.6 m. All scale bar gradations for figure 3.10 are in cm.

b) Tabular stromatoporoid (T) bindstone (Subfacies 9b) consisting of irregular and tabular (T) stromatoporoids having shelter cavity porosity partly infilled with saddle dolomite cement (SD). The photo is from 13-30-91-12W5, 1573.8 m.

c) Tabular stromatoporoid rudstone (Subfacies 9a) consisting of tabular stromatoporoids (T) and abundant fragmented and whole brachiopods (B) scattered through the dark brown bituminous mudstone to wackestone. The photo is from 2-2-92-13W5, 1631.9 m.

d) Tabular stromatoporoid bindstone (Subfacies 9b) consisting of tabular (T) and irregular stromatoporoids, separated by stylotized contacts or a grainstone (G) matrix. Uneven surfaces filled geopetally with calcite spar and micrite (below scale bar). The photo is from 13-30-91-12W5, 1578.8 m.


A
S
t
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T
SD
C
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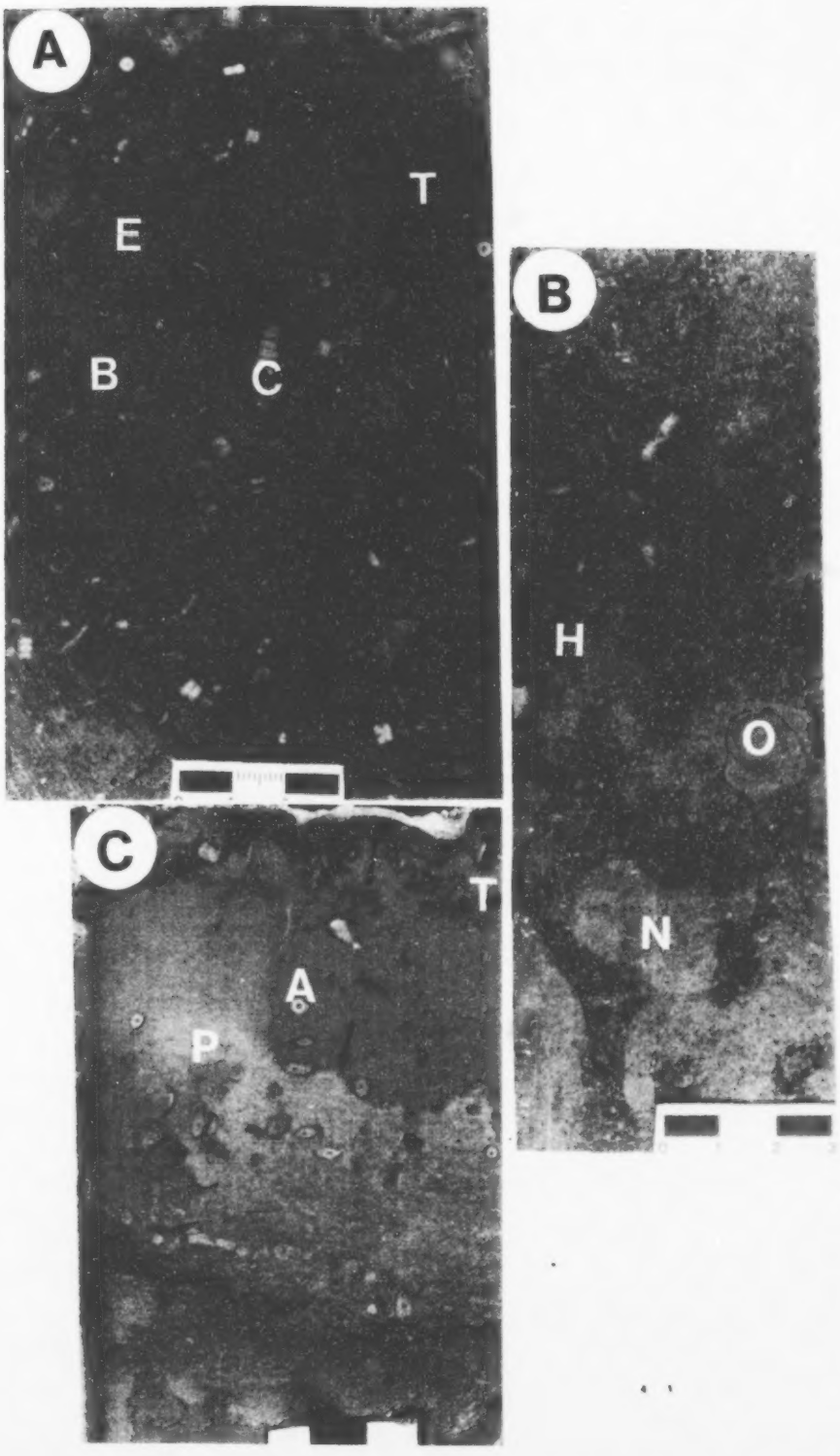
t
B
D
G
T

Figure 3.11 - Facies 10

a) Fossiliferous grainstone (Facies 10) consisting of peloids, irregular encrusting stromatoporoids (E), crinoids (C), branching coral fragments (T) and brachiopods (B). The photo is from 4-11-91-12 W5, 1613.7 m. All scale bar gradations for figure 3.11 are in cm.

b) Fossiliferous grainstone (Facies 10) consisting of a planar, mineralized hardground (H) in the facies. Nodular fabric (N) containing oncolites (O) and a matrix of skeletal packstones. Area between nodules (N) have a burrow-like form and consist of fossiliferous grainstones as found above the hardground. The photo is from 15-21-91-12W5, 1594.6 m.

c) Top contact of fossiliferous packstone consists of planar hardground (upwards arrow). The hardground is penetrated by *Trypanites* (T) and the surface consists of disseminated pyrite. Pyrite (P) occurs in small patches below the hardground surface. Mottled fabric consists of light and dark alternating patches (downwards arrow) containing *Amphipora* (A).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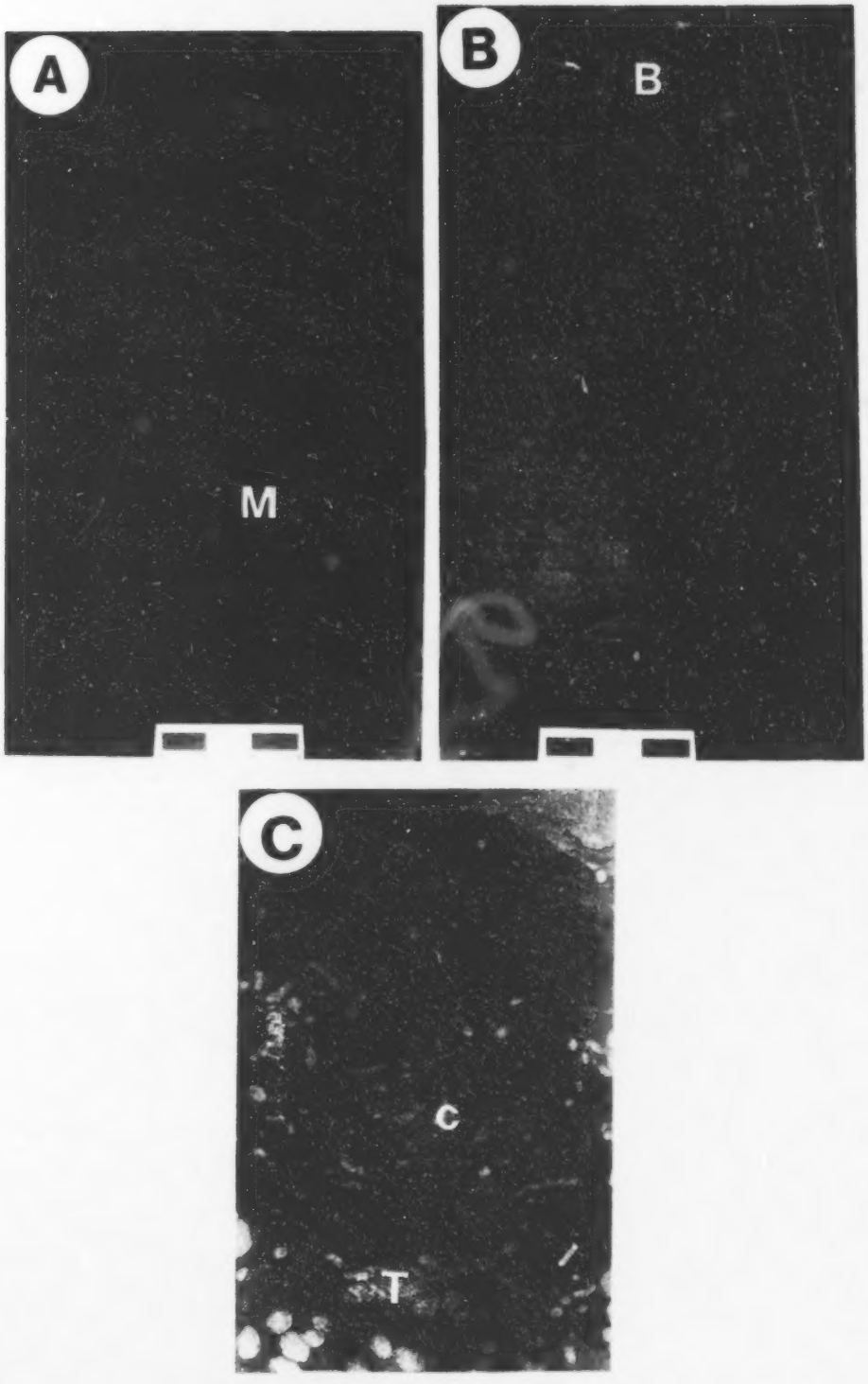
P

Figure 3.12 - Facies 11

a) Massive lime mudstone (Facies 11) consists of light brown mottled mudstone (M) overlain by dark brown bituminous mudstone (arrow). The photo is from 11-12-91-13W5, 1634.6 m. Scale bar gradations are in cm.

b) Massive lime mudstone (Facies 11) consists of dark brown bituminous mudstones containing brachiopods (B) separated by a light brown mudstone. The photo is from 8-7-91-12W5, 1640.1 m. Scale bar gradations are in cm.

c) Massive lime mudstone (Facies 11) consisting of microstylolites and scattered fragments of cylindrical stromatoporoids (C) and branching corals (T). The photo is from 16-29-91-12W5, 1593.3 m. Core width is 8 cm.


A
M
B
B
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C
T

CHAPTER 4: FACIES SUCCESSIONS AND DEPOSITIONAL HISTORY

4.1 INTRODUCTION

This chapter describes the depositional units of the Slave Point Formation in Sawn Lake field. The Slave Point Formation is informally divided into Divisions A, B, C, D and E (Fig. 4.1). Although these divisions can be traced across the field, only Division A can be easily traced off-field (Fig. 4.2, 4.3). Each division is characterized by an idealized facies succession which represents the most commonly recurring sequence of strata for each division. Although each division is discussed in terms of an idealized facies succession, a significant degree of heterogeneity occurs across the field. Where significant variations occur, a division is characterized by two facies successions that are areally restricted to specific portions of the field.

4.2 DIVISION DESCRIPTION AND INTERPRETATION

4.2.1 Division A

Distribution

Division A, comprised of unit a-1 and unit a-2, is widespread and uniform in thickness, averaging 10.9 m on-field and 6.0 m off-field (Fig. 4.3). Unit a-1 is thickest in the south part of the field whereas unit a-2, typically absent off-field, is thickest in the north part of the field.

Facies Succession

The idealized facies succession for Division A consists of Facies 1, Subfacies 2a, Facies 1, and Facies 3 (Fig. 4.4). Unit a-1 consists of

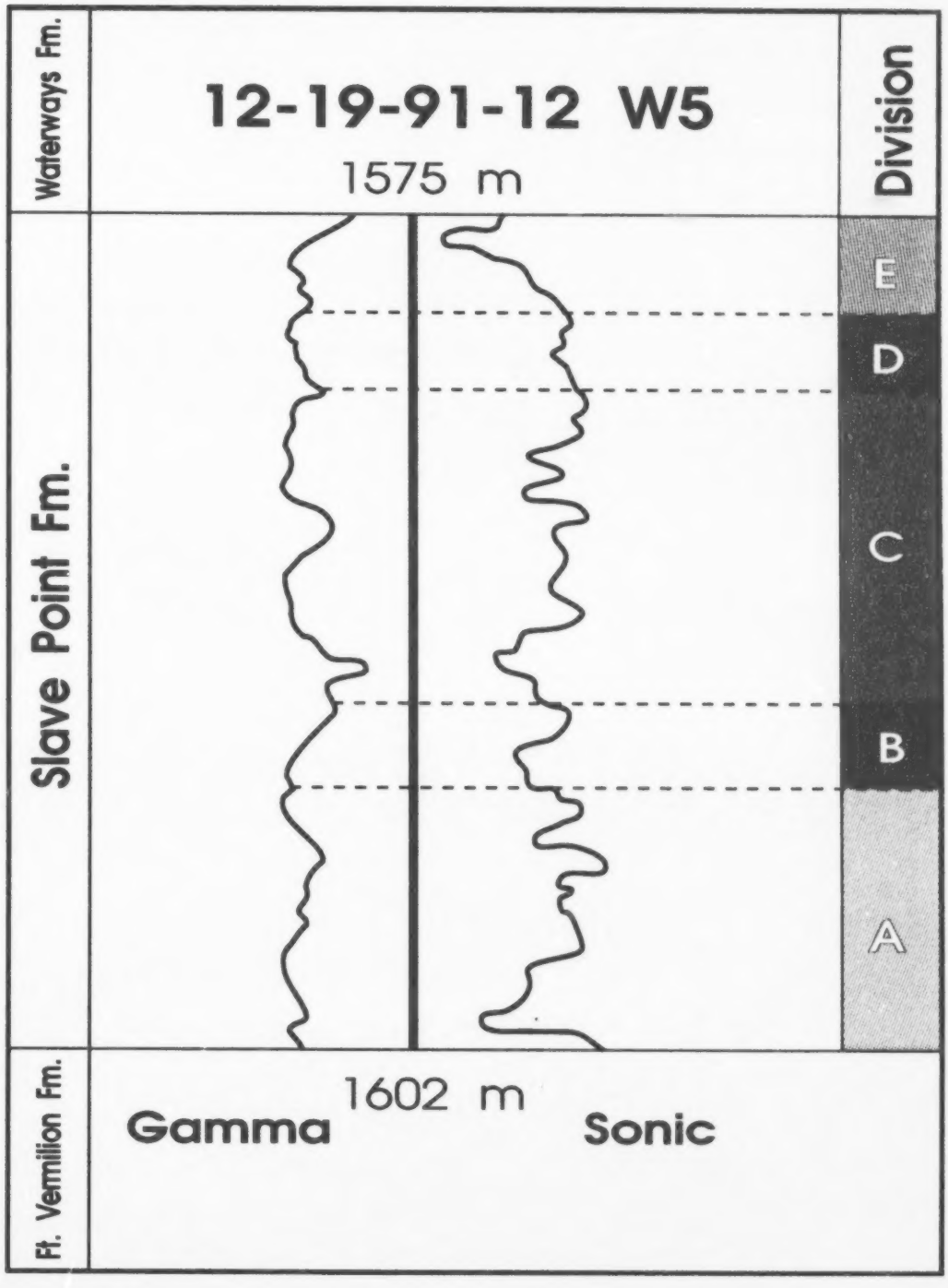
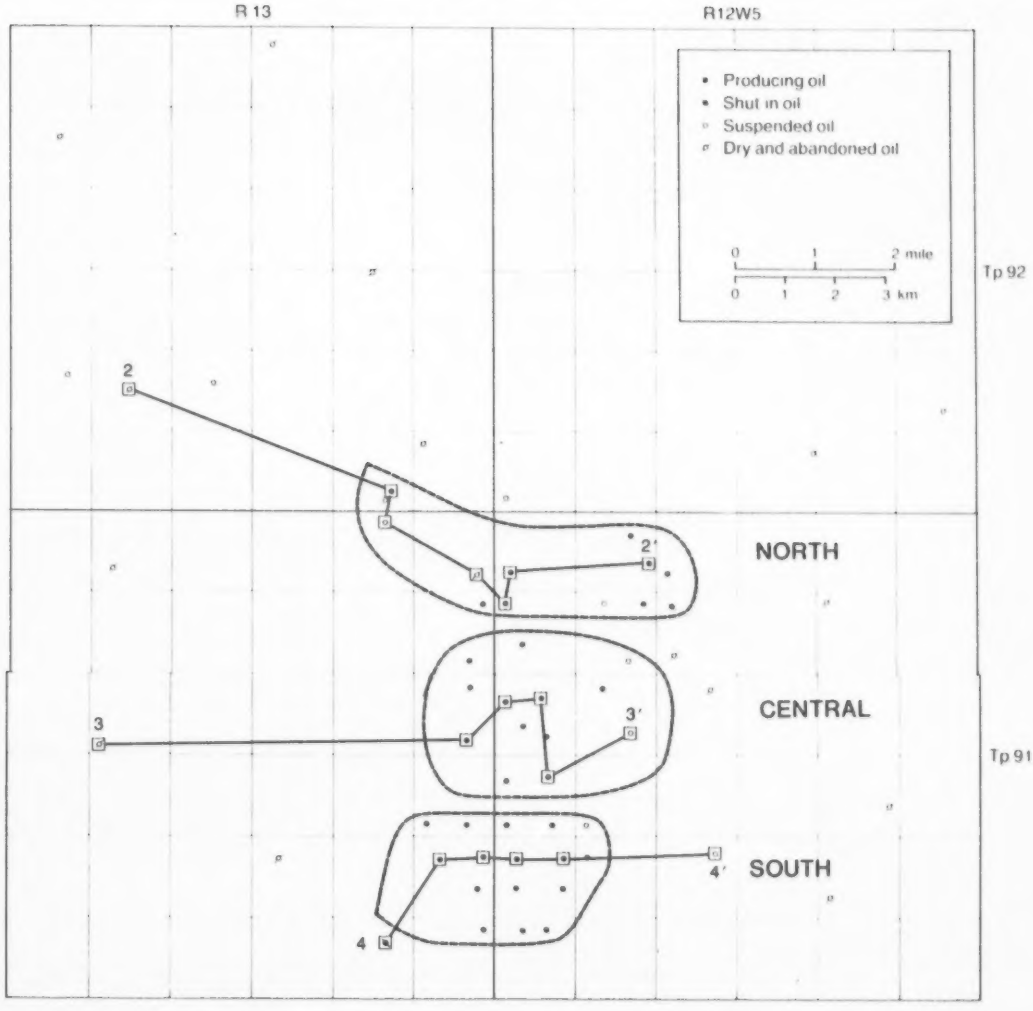


Figure 4.1 Type well for the Sawn Lake study area showing formal (left) and informal (right) stratigraphy.

Figure 4.2

Location of line and litholog cross-sections 2-2' through the north, 3-3' through the central and 4-4'through the south part of the Sawn Lake field.



Location Lithology Cross-sections

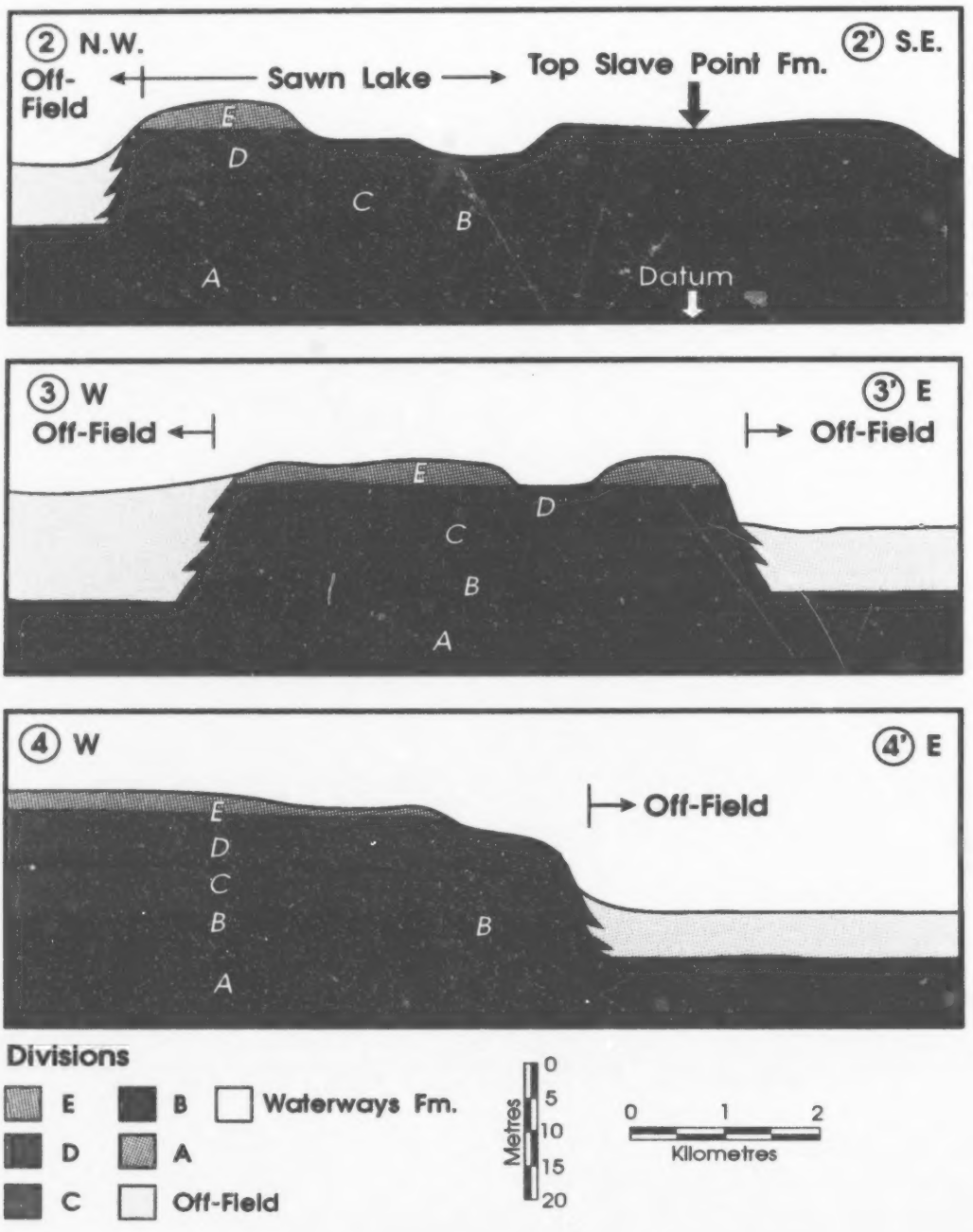


Figure 4.3 Stratigraphic line cross-sections through the north (2-2'), central (3-3'), and south (4-4') parts of the Sawn Lake field illustrating subdivision into five depositional units termed divisions.

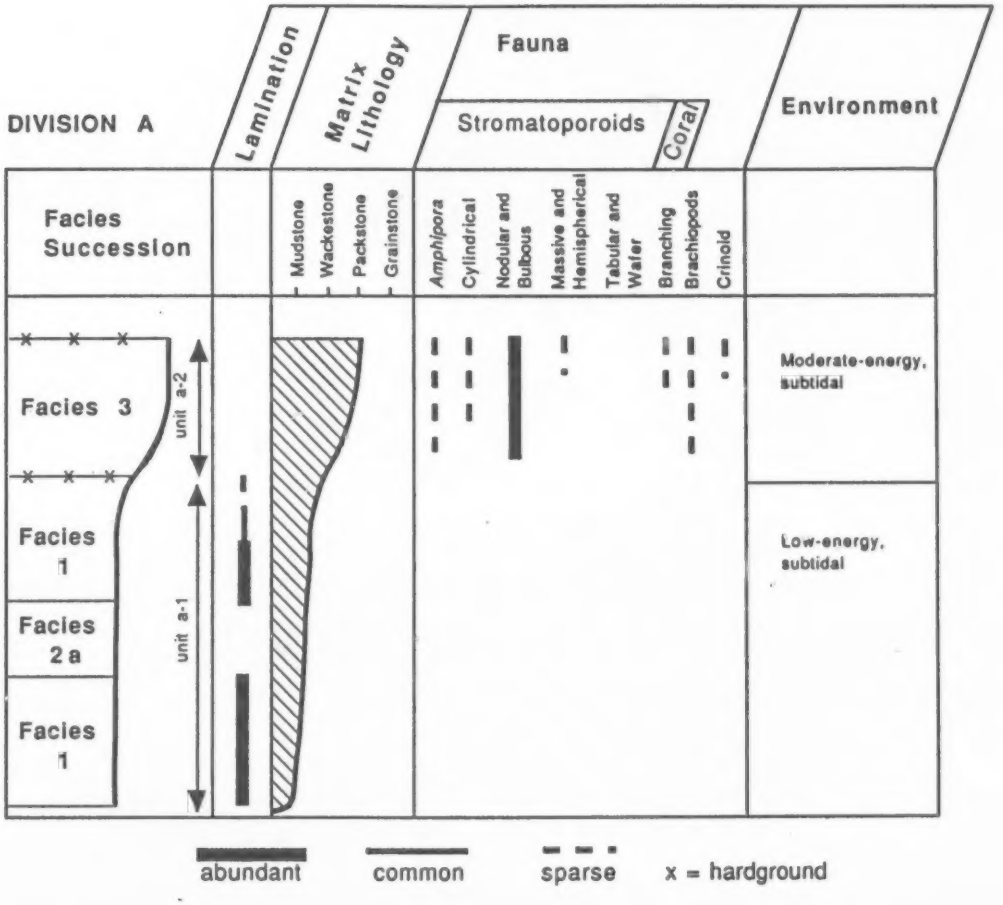


Figure 4.4 Schematic representation of Division A.

Facies 1 and Subfacies 2a, whereas unit a-2 consists of Facies 3. In Division A, facies contacts are generally gradational except for the contact between Facies 1 and Facies 3 that is commonly marked by a non-bored hardground. The upper contact of Division A is characterized by a bored, low relief hardground (Fig. 4.5 a).

Interpretation

The thinly-bedded, mud-supported limestones of Facies 1 that contain a pelagic fauna, and lack any evidence of peritidal origin, were probably deposited in low-energy, subtidal conditions (Fig. 4.4). The lack of current- or wave-related sedimentary structures in the laminated limestones (Facies 1) suggests deposition below fairweather wave base. Gosselin (1990) described a stratigraphically and lithologically similar facies in the Slave Point Formation at Golden and Evi and assigned it to deposition below fairweather wave base, at depths around 20 metres. The laminated limestones (Facies 1) probably developed at similar depths.

The gradational contact between Facies 1 and Subfacies 2a, in addition to their similar lithologies, suggests that deposition of Subfacies 2a also occurred in low-energy, subtidal conditions (Fig. 4.4). The absence of current or wave-related sedimentary structures in Subfacies 2a is suggestive of deposition below fairweather wave base. The development of an *in situ* nodular fabric, similar to that in the nodular mudstones (Subfacies 2a), may result from a combination of burrowing and selective early cementation (Kennedy and Garrison, 1975), accentuated by later compaction (Wanless, 1979). In Subfacies 2a, nodule boundaries are gradational with microstylolites which may reflect their concurrent growth and, therefore, *in situ* nodule

Figure 4.5

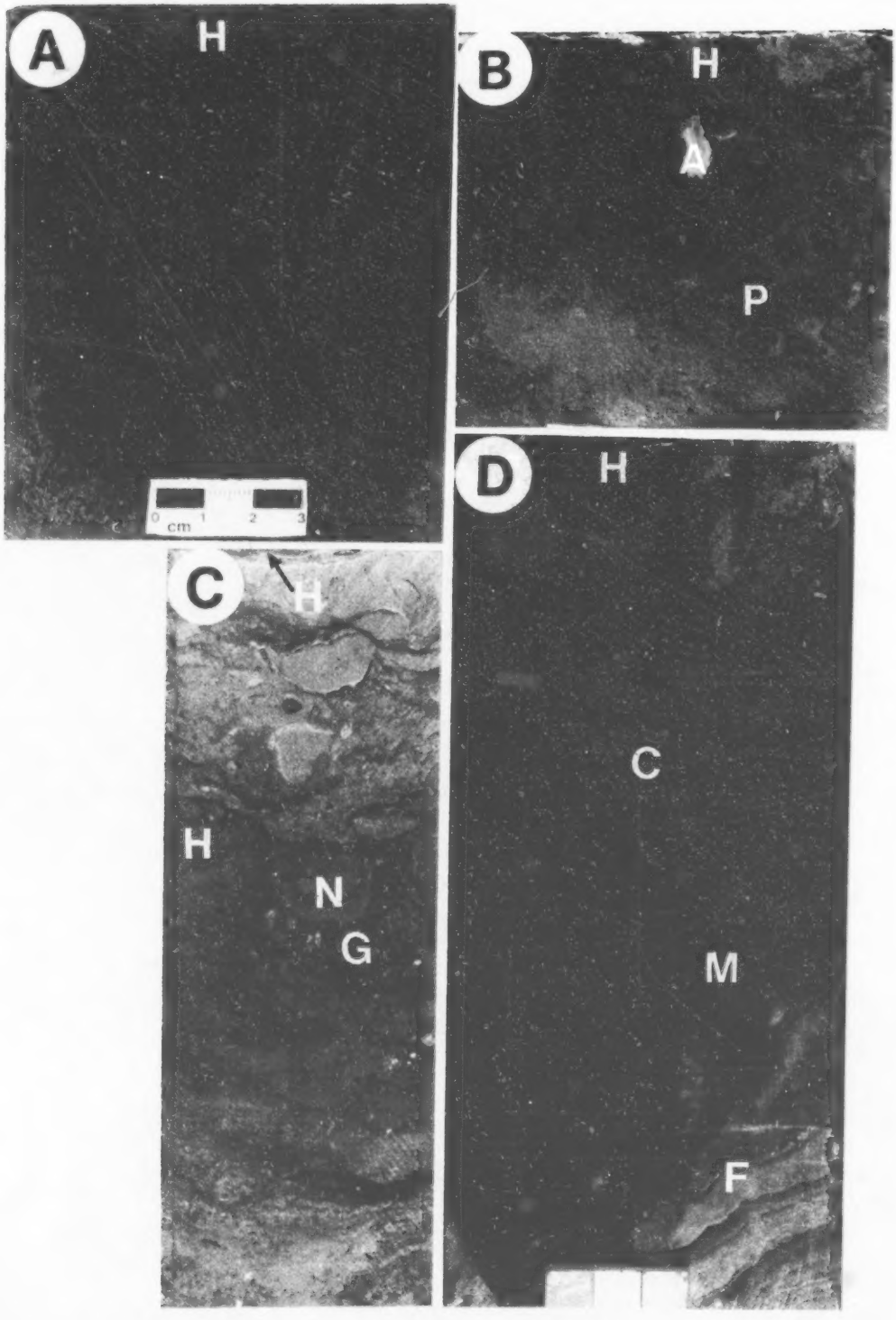
Core-photographs of submarine-cemented hardgrounds

a) Planar, pyritized hardground (H), located at the top of Division A, marked by a colour change that reflects a decrease in bituminous matter in the sediment overlying the surface. The photograph is from 4-11-91-12W5, 1613.8 m. Scale bar gradations are in cm.

b) Planar hardground (H) located at the top of the Slave Point Formation, on-field. The surface contains *Trypanites* filled with green argillaceous shale from the overlying Waterways Formation. A mottled fabric with disseminated pyrite (P) and sparse *Amphipora* occur in a nodular mudstone (Subfacies 2b). The photograph is from 9-7-91-12W5, 1610 m. Width of core is 9 cm.

c) Stacked, slightly undulatory hardgrounds (H) occur in an off-field, lower foreslope position. Underlying the pyritized hardground, in the center of the core, is a peloidal filled crevasse (G). The photograph is from 15-21-91-12W5, 1599.8 m. Width of core is 5 cm.

d) Pyritized, planar to hummocky hardground (H), containing cavities (C) (3.0 x 5.5 cm) filled with green shale of overlying Waterways Formation. A highly bituminous, microstylotized (M) matrix containing fragmented stromatoporoids (F) in a subspherical stromatoporoid floatstone. The photograph is from 15-24-91-13W5, 1568.3 m. Core width is 9 cm.


A
H
cm
B
H
A
P
C
H
H
N
G
D
H
C
M
F

development.

The upper part of unit a-1, characterized by biogenically reworked sediment, oncolites, and rare abraded cylindrical and nodular stromatoporoids is suggestive of deposition in moderate-energy conditions, around fairweather wave base (Fig. 4.4). The thickly-bedded (2 to 4 cm) laminated limestones (Facies 1) in the upper part of unit a-1 may have been deposited during a higher rate of suspension-sedimentation, perhaps due to slightly shallower water depths. The planar hardground capping the top of unit a-1 is relatively continuous across the field and may reflect a field-wide depositional hiatus.

The packstone matrix, allochthonous stromatoporoids and oncolites of Facies 3 (unit a-2) are attributed to deposition in moderate-energy subtidal conditions, around fairweather wave base (Fig. 4.4). The abraded nature of the stromatoporoids implies transportation by waves or currents during periods of higher-energy and subsequently bored and abraded during periods of lower-energy. The hardground at the top of Division A (Facies 3) is generally continuous across the field and may reflect another field-wide depositional hiatus. The submarine cementation of this hardground is suggested by the cross-cutting relationship of *Trypanites*, which indicates that earlier borings were cemented before development of later borings.

The sediments of the Slave Point Formation accumulated on a shallow carbonate platform where isolated reefs developed along the platform rim (Burrowes and Krause, 1987). The reefs on this rimmed platform correspond to the "reef complexes" (Craig, 1987; Dunham *et al.*, 1983; Davies and Tooth, 1987; Gosselin, 1990) located south of the Sawn Lake field (Fig. 2.5). The Slave Point Formation carbonate platform

evolved from the underlying carbonate ramp sediments of the Fort Vermilion Formation (Stoakes, 1988). In Division A, the widespread, low-energy, deeper-water limestones (Facies 1 and Subfacies 2a) of unit a-1 and the moderate-energy, shallower-water limestones (Facies 3) of unit a-2, probably represent deposition in a carbonate platform setting. The carbonate platform identified by Division A in the Sawn Lake area represents only a portion of the total area of the Slave Point Formation carbonate platform that extended around the Peace River Arch (Fig. 2.5).

4.2.2 DIVISION B

Distribution

Division B is from 0.6 to 4.1 m thick, with the thickest development occurring in the north part of the field (Fig. 4.3). Locally, Division B is thin or absent where stratigraphic highs on top of Division A occur, for example, at 7-2-92-13W5 (Fig. 4.6) and 11-7-91-12W5 (Fig. 4.7). This suggests that Division B filled the topographic lows of Division A.

Facies Succession

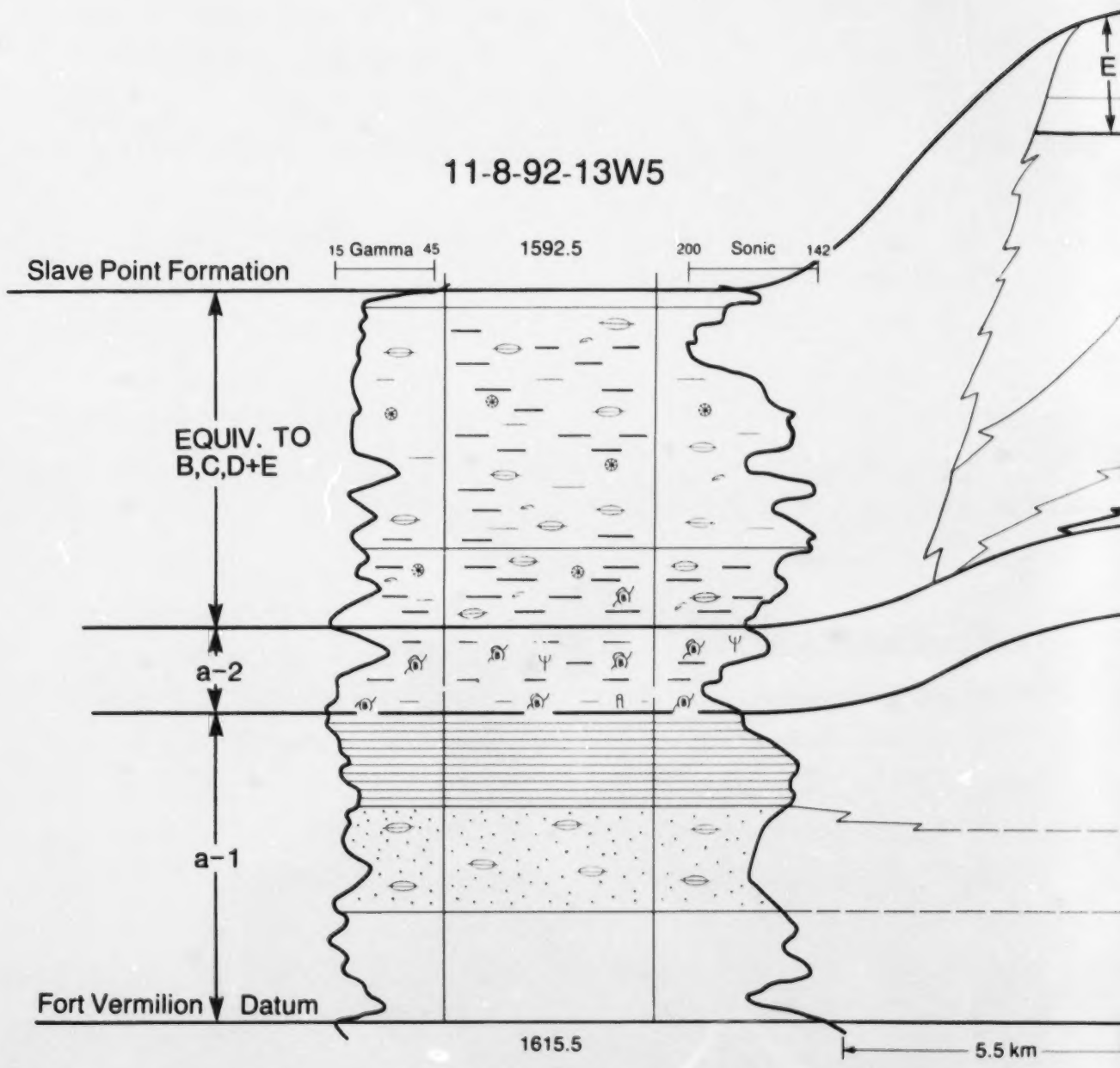
Division B is characterized by Facies 4 gradationally overlain by Facies 5, throughout all on-field areas (Fig. 4.8). These facies consist primarily of branching corals and cylindrical stromatoporoids in a wackestone to minor skeletal packstone matrix. Division B is difficult to trace to the off-field because of the mud-supported, sparsely fossiliferous sediments that occur there.

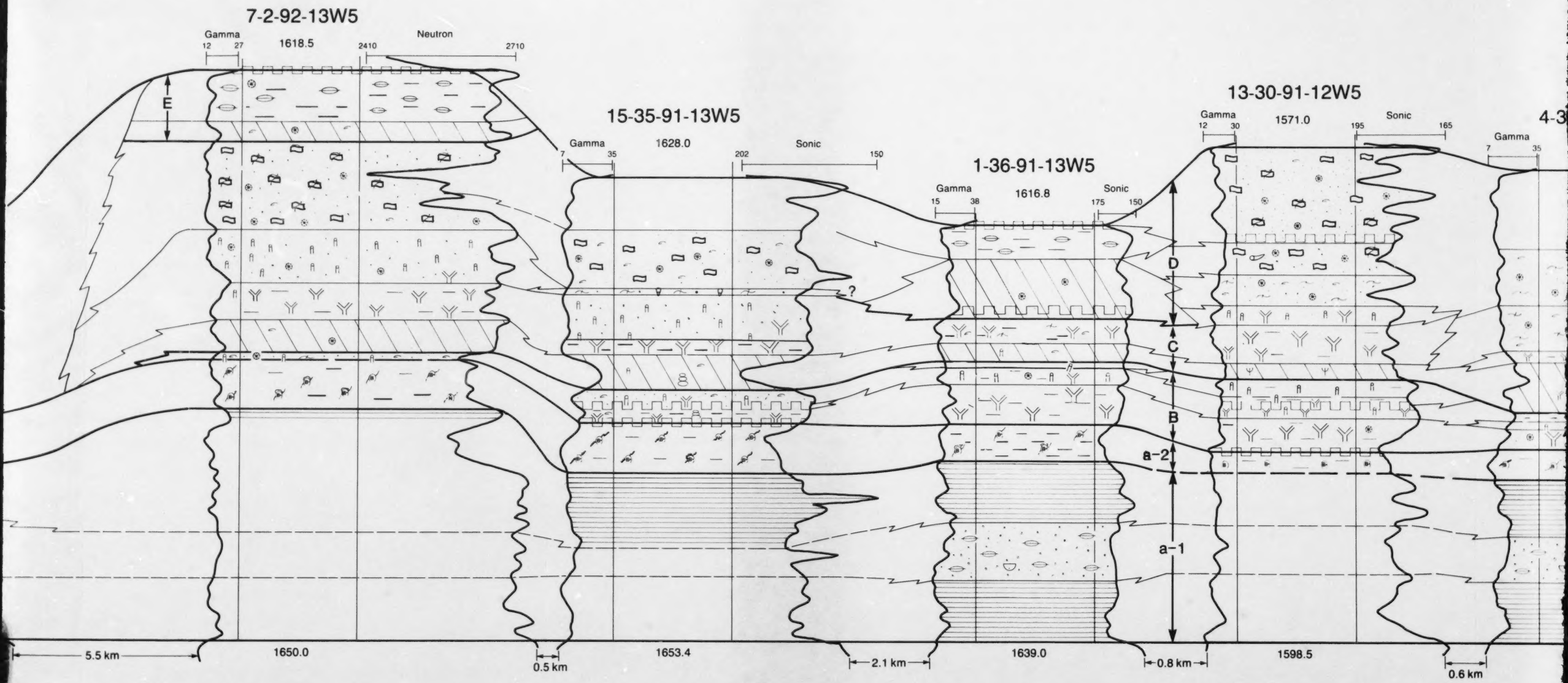
Figure 4.6

Litholog cross-section 2-2'

Stratigraphic litholog cross-section through the northern area of the Sawn Lake field, illustrating the distribution of divisions and their respective facies. The datum, at the base of the lithologs, marks the base of the Slave Point Formation and top of the Fort Vermilion Formation. Core measurements are in meters and symbols for facies in lithologs are located on the far right. Each litholog consists of two well-log curves with corresponding units, that include: a gamma curve (API units), and either a sonic curve (US/M units) or a compensated neutron lithodensity curve (k/mE3 units). Facies are separated by thin lines and divisions are indicated with thick black lines. Dashed black lines represent tentative correlation based on lack of cored data. Open white spaces on lithologs correspond to absence of core data. Distance between wells are shown along bottom of section in kilometers (km). The cross-section location is on Fig. 4.2.

2
NW


11-8-92-13W5
15 Gamma 45
1592.5
200 Sonic 142
Slave Point Formation
EQUIV. TO
B,C,D+E
a-2
a-1
Fort Vermilion Datum
1615.5
5.5 km
E


7-2-92-13W5
Gamma
12 27
1618.5
Neutron
2410 2710
E
15-35-91-13W5
Gamma
7 35
1628.0
202 Sonic 150
?
1-36-91-13W5
Gamma
15 38
1616.8
Sonic
175 150
13-30-91-12W5
Gamma
12 30
1571.0
195 Sonic 165
4-3
Gamma
7 35
D
C
B
a-2
a-1
5.5 km
1650.0
0.5 km
1653.4
2.1 km
1639.0
0.8 km
1598.5
0.6 km

2'
SE

13-30-91-12W5

1571.0

Sonic

195

165

4-31-91-12W5

Gamma

7

35

1595.2

193

Sonic

165

8-32-91-12W5

Gamma

8

30

1586.9

220

Sonic

160

EQUIV. TO
B,C,D+E

A

?

5

10

metres

1598.5

0.6 km

1621.0

2.9 km

1586.9

FACIES 1 — LAMINATED LIMESTONE

2A — NODULAR MUDSTONE

2B — NODULAR AND WAVY-BEDDED LIMESTONE

3 — NODULAR AND BULBOUS STROMATOPOROID FLOATSTONE

4 — BRANCHING CORAL RUDSTONE/FLOATSTONE

5 — CYLINDRICAL STROMATOPOROID RUDSTONE/FLOATSTONE

6 — FENESTRAL LIMESTONE

7A — LIGHT-BROWN *AMPHIPORA* FLOATSTONE/RUDSTONE

7B — DARK-BROWN *AMPHIPORA* FLOATSTONE/RUDSTONE

8 — SUBSPHERICAL STROMATOPOROID RUDSTONE

9A — WAFER STROMATOPOROID FLOATSTONE/RUDSTONE

9B — TABULAR STROMATOPOROID RUDSTONE/BINDSTONE

10 — FOSSILIFEROUS PACKSTONE/GRAINSTONE

11 — MASSIVE LIME MUDSTONE

Brachiopo

Gastropo

Crinoid o

Algal lam

Wafer st

Thick, en
stromat

Bored, e
abraded
stromat

Bioturbat

Ostracod

Rugose

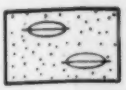
Hardgro

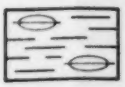
Predomi
matrix

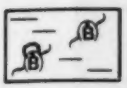
Predomi
matrix

Boring b

FACIES 1 LAMINATED LIMESTONE

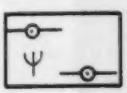
2A  NODULAR MUDSTONE

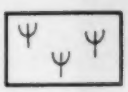
2B  NODULAR AND WAVY-BEDDED LIMESTONE

3  NODULAR AND BULBOUS STROMATOPOROID FLOATSTONE

4 BRANCHING CORAL RUDSTONE/FLOATSTONE

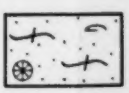
5 CYLINDRICAL STROMATOPOROID RUDSTONE/FLOATSTONE

6  FENESTRAL LIMESTONE

7A  LIGHT-BROWN *AMPHIPORA* FLOATSTONE/RUDSTONE

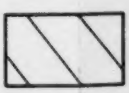
7B DARK-BROWN *AMPHIPORA* FLOATSTONE/RUDSTONE

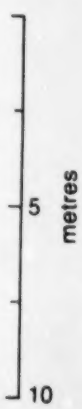
8 SUBSPHERICAL STROMATOPOROID RUDSTONE

9A  WAFER STROMATOPOROID FLOATSTONE/RUDSTONE

9B TABULAR STROMATOPOROID RUDSTONE/BINDSTONE

10 FOSSILIFEROUS PACKSTONE/GRAINSTONE

11  MASSIVE LIME MUDSTONE



 Brachiopod

Gastropod

Crinoid ossicle

Algal laminae

Wafer stromatoporoid

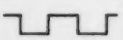
Thick, encrusted tabular **stromatoporoid**

Bored, encrusted, abraded bulbous **stromatoporoid**

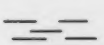
Bioturbation

Ostracods

Rugose coral

 Hardground

Predominantly grainstone matrix

 Predominantly mudstone matrix

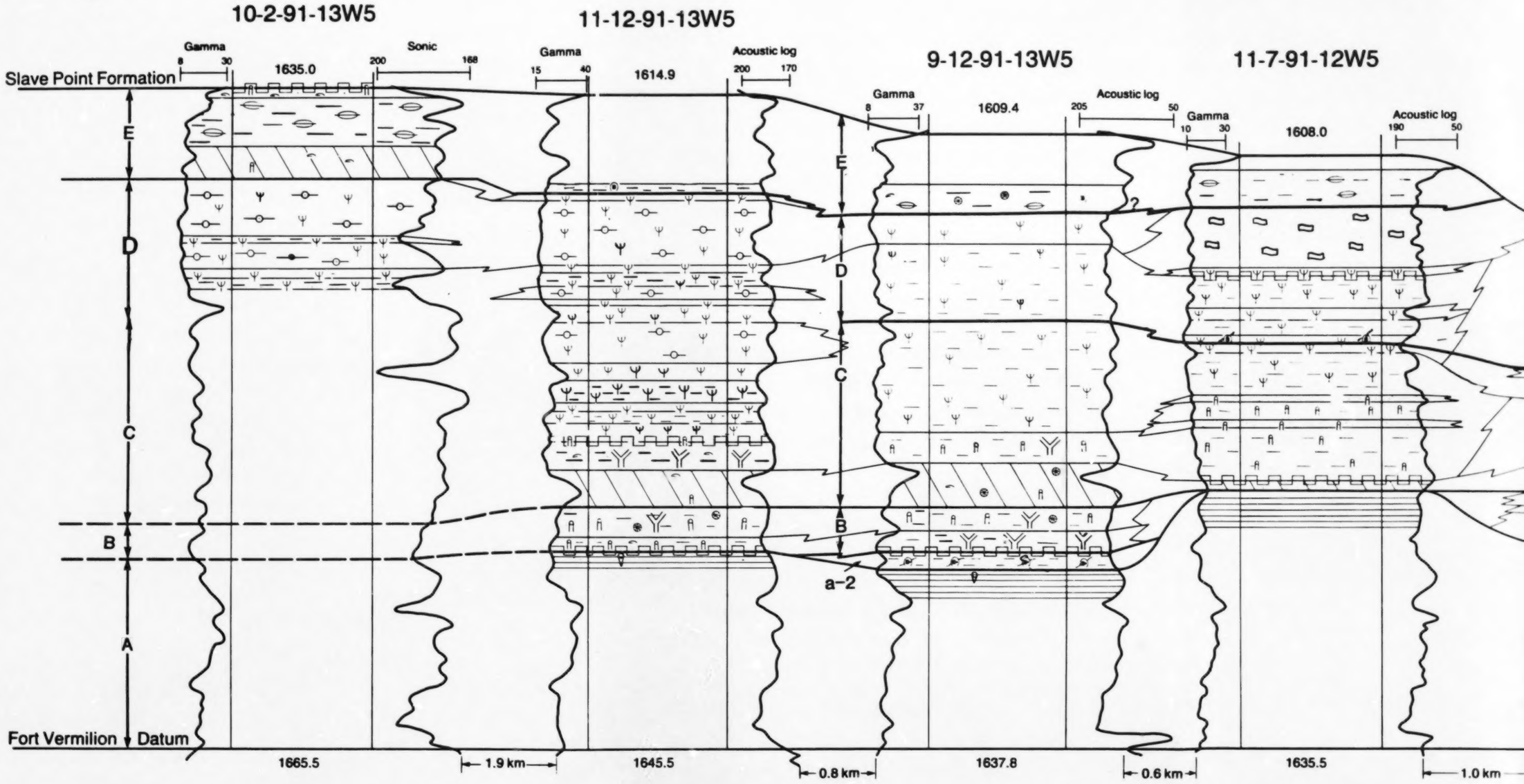
Boring bivalve

Figure 4.7

Litholog cross-section 4-4'

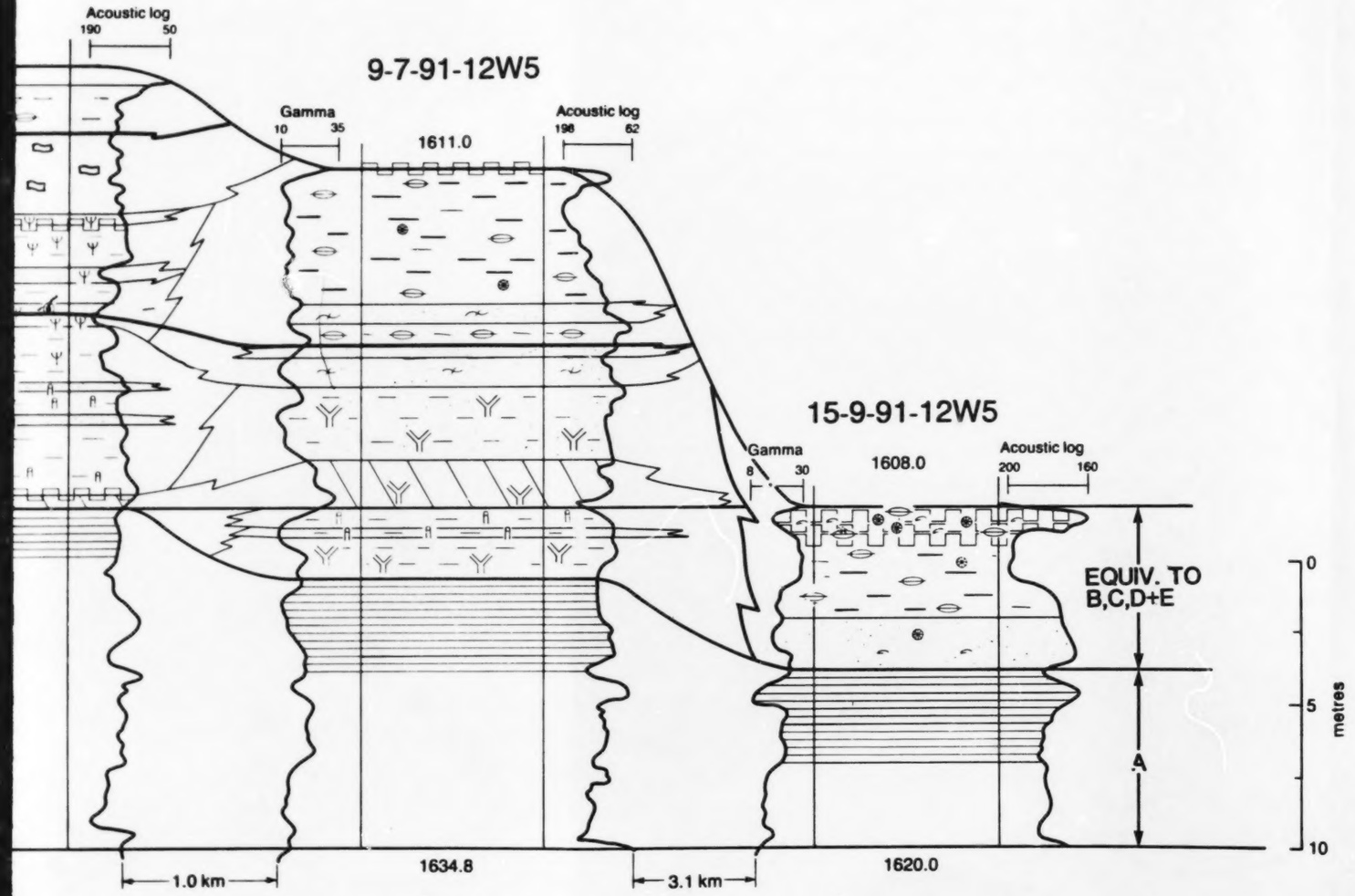
Stratigraphic litholog cross-section through the south part of the Sawn Lake field, illustrating the distribution of divisions and their respective facies. The datum, at the base of the lithologs, marks the base of the Slave Point Formation and top of the Fort Vermilion Formation. Core measurements are in meters and symbols for facies in lithologs are located on the far right. The cross-section is located on Fig. 4.2. See Fig. 4.6 caption for full description of diagram labels.

4
W


10-2-91-13W5
11-12-91-13W5
9-12-91-13W5
11-7-91-12W5
Gamma
Sonic
Acoustic log
1635.0
1614.9
1609.4
1608.0
Slave Point Formation
E
D
C
B
A
a-2
Fort Vermilion Datum
1665.5
1.9 km
1645.5
0.8 km
1637.8
0.6 km
1635.5
1.0 km

4′
E

2W5



FACIES 1 — LAMINATED LIMESTONE

2A — NODULAR MUDSTONE

2B — NODULAR AND WAVY-BEDDED LIMESTONE

3 — NODULAR AND BULBOUS STROMATOPOROID FLOATSTONE

4 — BRANCHING CORAL RUDSTONE/FLOATSTONE

5 — CYLINDRICAL STROMATOPOROID RUDSTONE/FLOATSTONE

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7A — LIGHT-BROWN *AMPHIPORA* FLOATSTONE/RUDSTONE

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9A — WAFER STROMATOPOROID FLOATSTONE/RUDSTONE

9B — TABULAR STROMATOPOROID RUDSTONE/BINDSTONE

10 — FOSSILIFEROUS PACKSTONE/GRAINSTONE

11 — MASSIVE LIME MUDSTONE

Brachiopod

Gastropod

Crinoid ossicle

Algal laminae

Wafer stromatoporoid

Thick, encrusted tabular **stromatoporoid**

Bored, encrusted, abraded bulbous **stromatoporoid**

Bioturbation

Ostracods

Rugose coral

Hardground

Predominantly grainstone matrix

Predominantly mudstone matrix

Boring bivalve

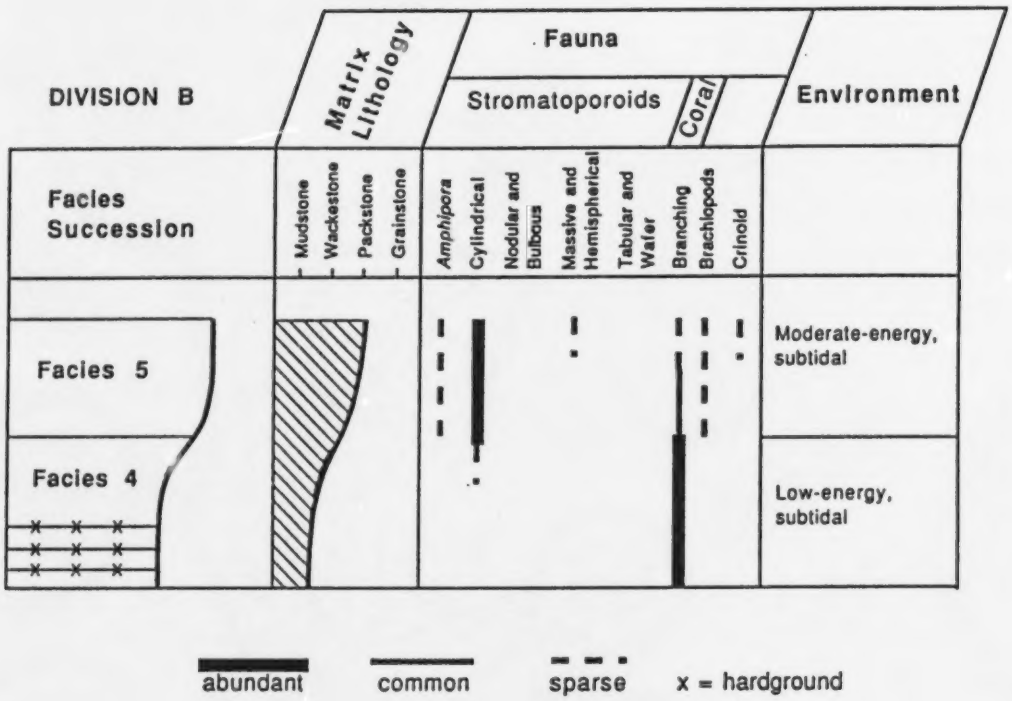


Figure 4.8 Schematic representation of Division B.

Interpretation

The presence of normal marine fauna (cylindrical corals and stromatoporoids) and the lack of evidence for subaerial exposure in Facies 4 and 5 suggests that deposition occurred in shallow-marine waters, between low tide and fairweather wave base or the base of the euphotic zone (Fig. 4.8). The fauna probably developed in place based on their high density and lateral distribution. Locally, some cylindrical corals and stromatoporoids are abraded, probably due to storm activity. In general, branching corals are indicative of deposition in low-energy, muddy environments, whereas cylindrical stromatoporoids developed under better-circulated, moderate-energy conditions (Kobluk, 1978). The moderately-diverse fauna in Facies 5 is indicative of better- circulation, whereas the low-diversity of fauna in Facies 4 implies poor-circulation (Fig. 4.8). The lack of bituminous matter and generally coarser-grained matrix in Facies 5 is suggestive of deposition in moderate-energy or periodically turbulent conditions, whereas the predominantly fine-grained bituminous matrix in Facies 4, indicates the influence of lower-energy conditions. The laterally discontinuous, stacked hardgrounds in Facies 4 probably formed during short breaks in sedimentation.

The facies of Division B represent deposition of a stromatoporoid and coral shoal, in a moderate- to well-circulated, open-marine setting. Water depths were probably between intermediate to shallow-marine water depths. This shoal corresponds to the on-field area of Sawn Lake, whereas the facies of Division A are widespread, extending over the field and off-field area (line cross-section 3-3', Fig. 4.3). The shallow-marine facies of Division B interfinger with

deeper-water mudstones and wackestones (Subfacies 2b) of the off-field area. In Division B, the transition from the field to the off-field is marked by a slight break in slope (7-2 to 11-8, Fig. 4.6 and 9-7 to 15-9, Fig. 4.7). The development of a carbonate shoal (Division B) over the on-field area may have been initiated due to a subtle pre-Slave Point Formation paleotopographic high originating on the Precambrian surface (Fig. 2.6). This relative structural high would influence the initial establishment and growth of reef-type organisms in Facies 4 and Facies 5.

4.3.3 DIVISION C

Distribution

Division C has a wedge-shaped profile, being 4.0 m thick in the north, 9.5 m in the center, and 12.3 m in the south (Fig. 4.3). The variable thickness of Division C probably reflects variable rates of carbonate production and accumulation over the field. The facies of Division C interfinger off-field with deeper-water mudstones and wackestones (Subfacies 2b).

Facies Succession

Division C consists of facies successions C-1 and C-2 that generally occur in in the northeast and southwest parts of the field, respectively. Succession C-1 consists of Facies 11, Facies 4, Facies 5 or Facies 10, and Subfacies 9a or 9b (Fig. 4.9). Succession C-2 consists of Facies 11, Facies 5 or Facies 8, Subfacies 7b, Subfacies 7a, and Facies 6 (Fig. 4.10).

The lower part of facies successions C-1 (Fig. 4.9) and C-2 (Fig.

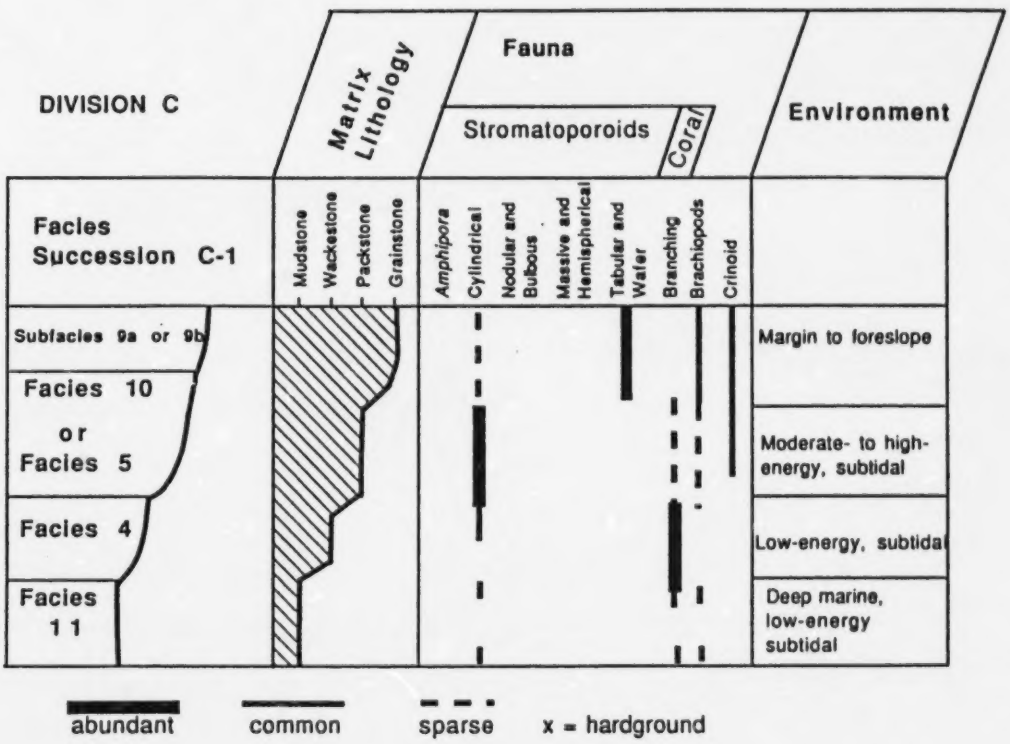


Figure 4.9 Schematic representation of Division C, facies succession C-1.

4.10) consists of dark lime mudstone (Facies 11) grading upwards into Facies 5. Locally, in facies succession C-1, a thin unit of Facies 4 may separate Facies 11 from Facies 5 (Fig. 4.9). The upper part of facies successions C-1 and C-2, comprised of all facies that overlie Facies 5, represent a number of different depositional environments.

Interpretation

During deposition of the Slave Point Formation the dominant winds were from the northeast (Wendte and Stoakes, 1987). These dominant winds influenced the development of higher-energy facies in shallow-marine water depths, on the northern and eastern edges of the Sawn Lake field. The higher-energy facies, located in the upper part of Division C, formed protective reef margins that resulted in the development of distinct facies belts (e.g., foreslope, reef flat, and reef interior). The facies in the lower part of Division C represent laterally extensive, low- to moderate-energy limestones that were not as influenced by the dominant winds because of their development in intermediate water depths.

In the lower part of facies succession C-1 and C-2, Facies 11 is relatively thin (0.6 to 3.4 m) and widespread across the field (Fig. 4.6, 4.7). The fine-grained, bituminous matrix and lack of fauna in Facies 11 suggests deposition in low-energy, subtidal conditions (Fig. 4.9). The fauna, which occurs in the lower- and uppermost centimeters of Facies 11, is not *in situ* and was probably derived from reworking of skeletal elements in Facies 5 of Division B. Laminations which are commonly developed in low-energy subtidal settings, are absent in Facies 11. The lack of lamination is attributed to rapid deposition,

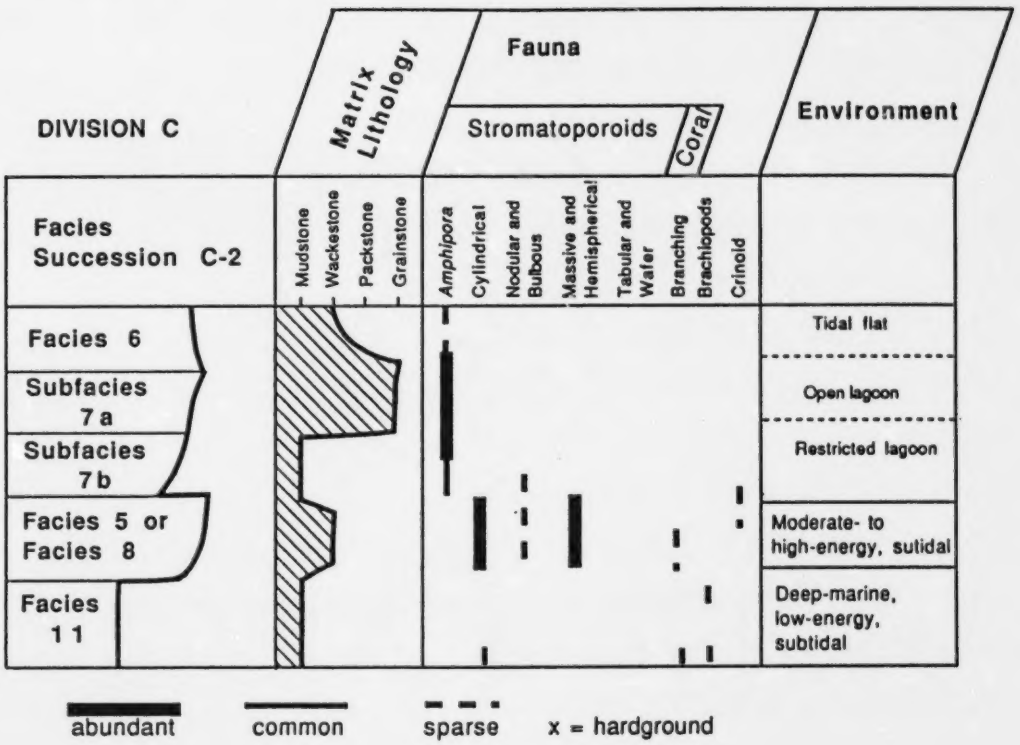


Figure 4.10 Schematic representation of Division C, facies succession C-2.

biogenic reworking, and/or lack of mineralogical contrast in the homogeneous mudstones. The lack of current- or wave-related sedimentary structures suggests deposition below fairweather wave base. Mudstones similar to Facies 11 could develop in a subtidal lagoon setting. However, the widespread occurrence of Facies 11, the absence of characteristic lagoonal fauna (e.g. *Amphipora*) and features is more suggestive of an open-marine, subtidal setting.

A sharp change in depositional conditions is represented by the transition between Facies 5, in the upper part of Division B, and Facies 11, in the lower part of Division C (Fig. 4.9, 4.10). This transition represents a change from a moderate-energy, shallow-marine setting around fairweather wave base (Facies 5 in Division B) to a low-energy, subtidal setting below fairweather wave base (Facies 11). The termination of Facies 5 (Division B) may be the result of adverse environmental conditions that reduced the growth potential of the shallow-marine organisms in that facies. An alternative explanation is that a relative sea level rise introduced deeper water conditions that would have exceeded the growth potential of the organisms developed in Facies 5 (Division B). However, the termination of shallow-marine carbonates due to a relative sea level rise is not widely accepted because under favorable conditions carbonate platforms and reefs have been shown to grow at rates that match the fastest known sea level rises during the Holocene (Kendall and Schlager, 1981). The mudstones (Facies 11) were gradually deposited in depths approaching fairweather wave base and indicated by the vertical transition to shallow-marine organisms (cylindrical corals and stromatoporoids) in Facies 4 and/or Facies 5 (Division C).

In the lower part of facies successions C-1 and C-2, Facies 4 and Facies 5 represent deposition in low- to moderate-energy, subtidal conditions (Fig. 4.9, 4.10). The abundant branching corals, fine-grained bituminous matrix, and low diversity of fauna in Facies 4 is attributed to deposition in low-energy, subtidal conditions below fairweather wave base (Fig. 4.9). The cylindrical stromatoporoids and moderate-diversity of fauna in Facies 5 suggests deposition in moderate-energy, subtidal conditions (Fig. 4.9). The lack of bituminous matter and slightly coarser matrix in Facies 5 is indicative of higher-energy conditions, around fairweather wave base. Deposition of Facies 4 and 5 in Division C probably occurred in water depths around 15 to 20 m and are similar to water depths postulated for deposition of Facies 4 and 5 in Division B.

Moderate- to well-sorted fossiliferous packstones and grainstones (Facies 10), laterally transitional with Facies 5, are indicative of deposition during constant current activity, around fairweather wave base (Fig. 4.11). The medium- to coarse-grained skeletal debris is derived from stromatoporoid and coral production in adjacent areas. The grainstones (Facies 10) were deposited as a medium- to coarse-grained talus around the eastern perimeter of the field. The local development of slightly undulatory hardgrounds in Facies 10 (Fig. 4.5c) probably represents local periodic pauses in sedimentation.

The laterally extensive succession of facies in the lower part of Division C (Facies 4, 5 or 10) represent deposition of a carbonate shoal. The carbonate shoal represented in Division C differs from the shoal represented in Division B, because the former acts as the buildup upon which facies belts (reef margin, foreslope, reef flat, and reef

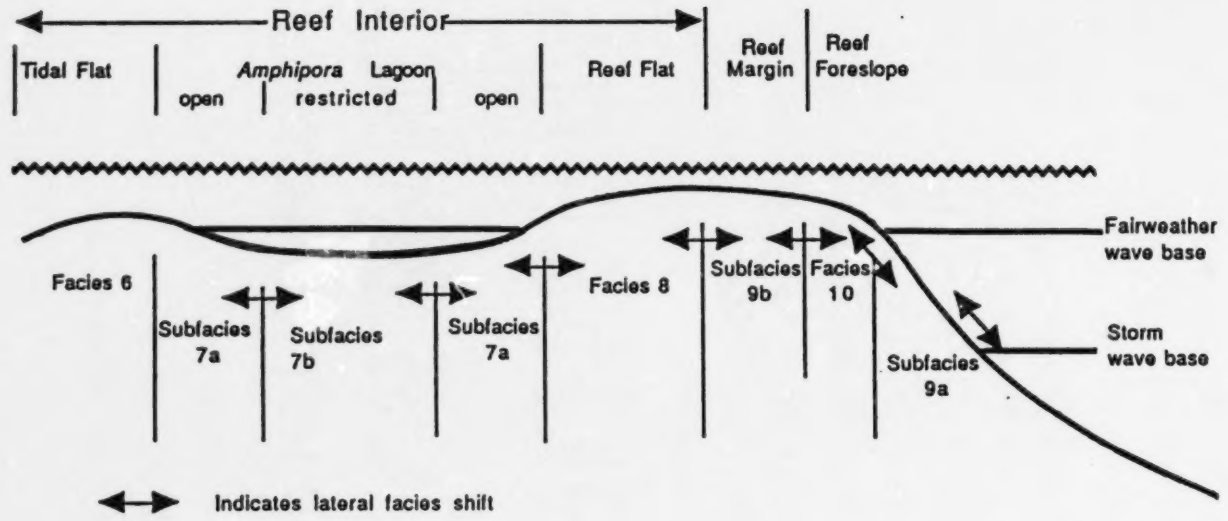


Figure 4.11 Schematic representation of Division C and D.

interior) of an isolated reef develop.

Reef margin

The tabular stromatoporoid rudstones and bindstones (Subfacies 9b), in the upper part of facies succession C-1, represent deposition in a reef margin setting (Fig. 4.11). This facies consists primarily of tabular stromatoporoid bindstones with common encrusting and cylindrical stromatoporoids, in a minor packstone and grainstone matrix. The paleoecology of tabular stromatoporoids is rather controversial. For example, Stearn (1975) and Kobluk (1978) proposed that tabular stromatoporoids could inhabit the shallow agitated environment of the reef margin (Fig. 4.12). In contrast, Fischbuch (1968) and Embry and Klovan (1971) suggested that tabular stromatoporoids could occupy a relatively deep foreslope environment. However, the broad basal attachment of tabular stromatoporoids implies the necessity for a high level of mechanical stability in a shallow agitated environment. In addition, their flattened form suggests that they must inhabit environments characterized by a low rate of sedimentation, otherwise, they could be rapidly smothered. The high-energy conditions at the reef margin would have a relatively low rate of sedimentation due to winnowing of fine material that is swept behind the margin. Based on these deductions, the thick tabular stromatoporoids (Subfacies 9b) are suggestive of deposition in moderate- to high-energy, well-circulated conditions of the reef margin (Fig. 4.11). The stability of the tabular stromatoporoids in Subfacies 9b is further enhanced by their ability to encrust and form bindstones through successive encrustations. The reef margin in Division C represents a relatively narrow area in the

Figure 4.12: The zonation of stromatporoid forms across a carbonate complex. The height of the band represents relative abundance (after Kobluk, 1978).

northeast corner and a narrow strip along the eastern flank of the field (Fig. 4.13).

Reef foreslope

The wafer stromatoporoid floatstones and rudstones (Subfacies 9a), in the upper part of facies succession C-1, represent deposition in a foreslope setting (Fig. 4.11). This facies consists of wafer stromatoporoids, and subordinate tabular and cylindrical stromatoporoids in a grainstone and packstone matrix (Fig. 4.9). The thin, flattened form of wafer stromatoporoids, in contrast to the thick tabular stromatoporoids, suggests that the former occupied an environment having low light, more limited nutrient availability, and less agitation. Therefore, deposition of Subfacies 9a is suggested to have occurred in a low to moderate-energy setting seaward of the reef margin, in a foreslope setting (Fig. 4.11). The foreslope limestones consist of both moderate-energy, *in situ* deposits which typify the lower and middle foreslope and higher-energy, allochthonous deposits derived from the physical and biological breakdown of the shallow-water reef complex. The upper foreslope environment would represent deposition around fairweather wave base. The middle and lower foreslope environment would represent deposition between fairweather and storm wave base, in water depths from 10 m to a few tens of meters (Fig. 4.11).

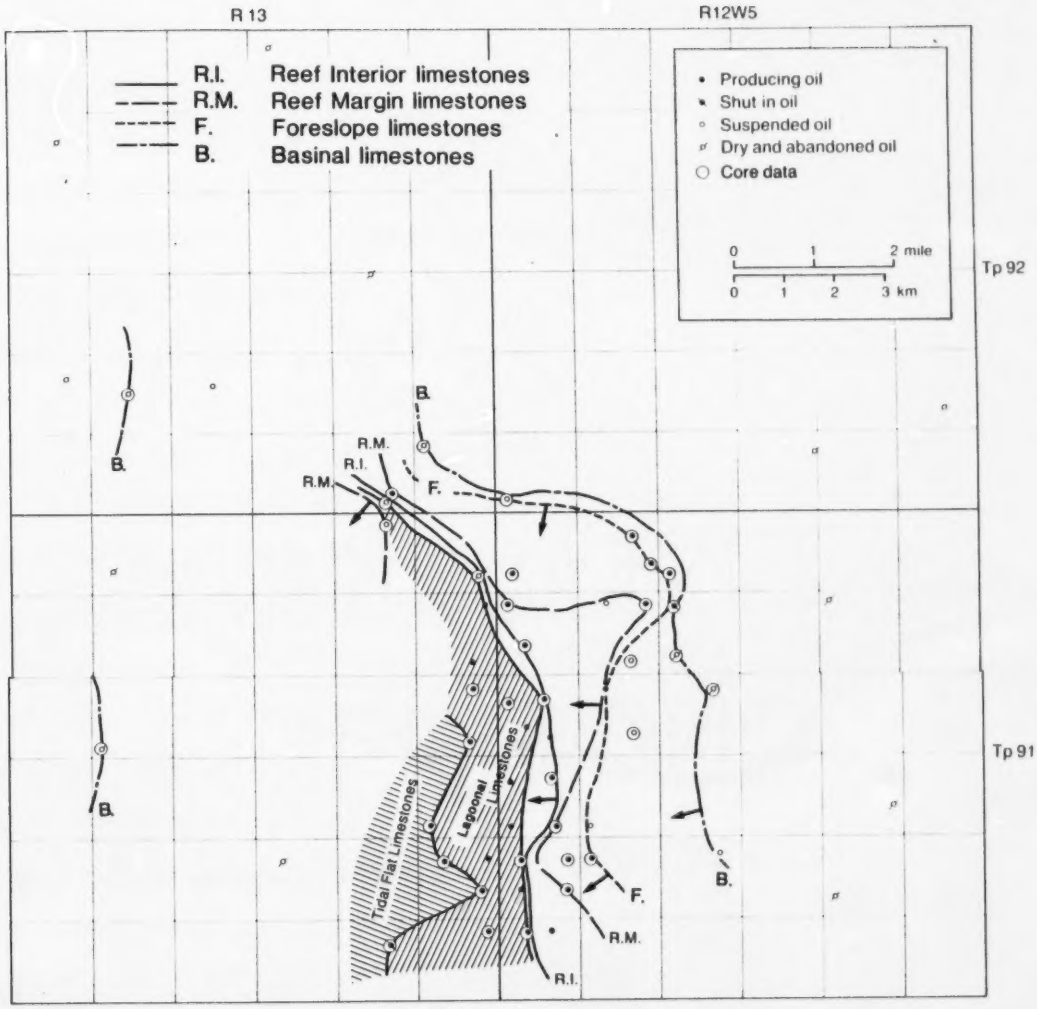
Reef interior

The subspherical stromatoporoid rudstones (Facies 8), in facies succession C-2, represent deposition in a reef flat setting of the reef

Figure 4.13

Distribution of depositional environments in Division C

Location map of the depositional environments interpreted from the facies successions of Division C. The depositional environments include the reef interior (R.I.), the reef margin (R.M.), the foreslope (F.) and the basinal (B.) limestones. Each depositional environment covers an area between adjacent lines, each representing the border of a particular environment. For example, the foreslope limestones (F.) are bounded on the east by the short-dashed line and extend west of this line to the long-dashed line representing the eastern limit of the reef margin limestones (R.M.). The reef interior (R.I.) includes the area denoted tidal flat limestones and *Amphipora* limestones, that would correspond to the reef interior cycle described in the text, and that is bounded by the line marked reef interior (R.I.). The dot-dashed line representing the eastern limit of the basinal limestones (B.) corresponds to their limit identified in core. The basinal limestones of Division C probably extend east of this limit but core data were not available to back this up.



Distribution of Depositional Environments Division C

interior (Fig. 4.11). This facies consists of medium- to light-brown packstones, breccias, grainstones and local bindstones. The abundance of interlocking hemispherical and massive stromatoporoids (Fig. 4.12) and exclusion of delicate stromatoporoid morphotypes in the matrix-free intervals of Facies 8 suggests deposition in a moderate- to high-energy setting, on the leeward side of the margin. The presence of nodular and bulbous stromatoporoids in Facies 8 are indicative of deposition in moderate-energy conditions, closer to the lagoon while the hemispherical stromatoporoids are indicative of deposition near the margin (Fig. 4.12). Typically, these limestones (Facies 8) are matrix-poor or the matrix is comprised of peloid grainstone and packstones suggestive of relatively high-energy conditions. Locally, abundant *Amphipora* and subspherical stromatoporoids in a mudstone matrix are suggestive of transportation of the subspherical stromatoporoids from an environment of high-energy to one of low-energy. Deposition in the reef flat environment occurred around fairweather wave base and in water depths of less than 10 meters (Fig. 4.11). The reef-flat setting of Division C (Facies 8) is located to the west of the reef margin (Fig. 4.13).

The *Amphipora* limestones (Subfacies 7a and 7b), in the upper part of facies succession C-2, represent deposition in a lagoon setting of the reef interior (Fig. 4.10). Locally, the transition of Subfacies 7b overlain by Subfacies 7a occurs twice in a single well (11-12-91-13W5, Fig. 4.7). In the dark brown *Amphipora* floatstones and rudstones (Subfacies 7b), the interstitial lime mud, poor sorting, and low faunal diversity, dominated by *Amphipora* (Fig. 4.12), is indicative of deposition in a restricted lagoon setting, characterized by low-energy and abnormal salinities (Fig. 4.10). Water

depths in the restricted lagoon would be in the subtidal range, below fairweather wave base (Fig. 4.11).

In the light-brown *Amphipora* floatstones and rudstones (Subfacies 7a), the greater abundance of *Amphipora* (Fig. 4.12), absence of bituminous material, and lighter colour of the matrix is suggestive of deposition in an open or non-restricted lagoon (Fig. 4.10). Peloidal packstones and grainstones are also locally common in Subfacies 7a and were probably deposited in higher-energy zones around the shoreline of the lagoon. The open lagoon setting would be characterized by deposition in moderate-energy subtidal conditions, around fairweather wave base (Fig. 4.11). The lagoon environment, consisting of *Amphipora* limestones (Subfacies 7a and 7b) is located in the southwest part of the field and to the west of the reef-flat (Fig. 4.13).

In facies succession C-2, Subfacies 7a is overlain by the fenestral limestones (Facies 6). In Facies 6, the presence of fenestrae, algal-laminae, and paucity of fauna is suggestive of deposition in a tidal-flat setting (*cf.* Wong and Oldershaw, 1980; Hardie, 1986). The lagoon (Facies 7) and tidal-flat (Facies 6) environments are well-developed in the extreme southwest part of the field (Fig. 4.13).

In Division C, the lower portion of facies successions C-1 and C-2 are represented by deposition in low-energy, subtidal waters (Facies 11) probably greater than 20 m in depth. This mudstone (Facies 11) vertically aggrades to sediments that are deposited in shallow-marine waters (Facies 4, 5 and 10), probably in 10 to 20 m water depth. These facies represent deposition of a carbonate shoal based on their

laterally continuous extent across the field, their homogeneous lithology, deposition in intermediate to shallow-marine waters and lack of development of facies belts. The carbonate shoal formed the base upon which the isolated reef developed.

The upper portion of facies successions C-1 and C-2 represent deposition across an isolated reef, characterized by a wide range of facies belts (foreslope, margin, reef flat and reef interior). These reefal facies were generally deposited above fairweather wave base and in water depths from 0 to 20 meters. The isolated reef has an asymmetrical profile, where the reef-margin is well developed on only the north and eastern edges of the field (Fig. 4.13). This isolated reef (Division C) probably occurs reasonably close to the edge or rim of the Slave Point Formation carbonate platform because there have been no other fields discovered to the east of Sawn Lake or other Slave Point fields to the south. In addition, underlying structural contours on pre-Slave Point Formation markers indicate a north-south trend that suggests the position of the rim or edge of the Slave Point Formation carbonate platform (Fig. 2.5).

4.2.4 DIVISION D

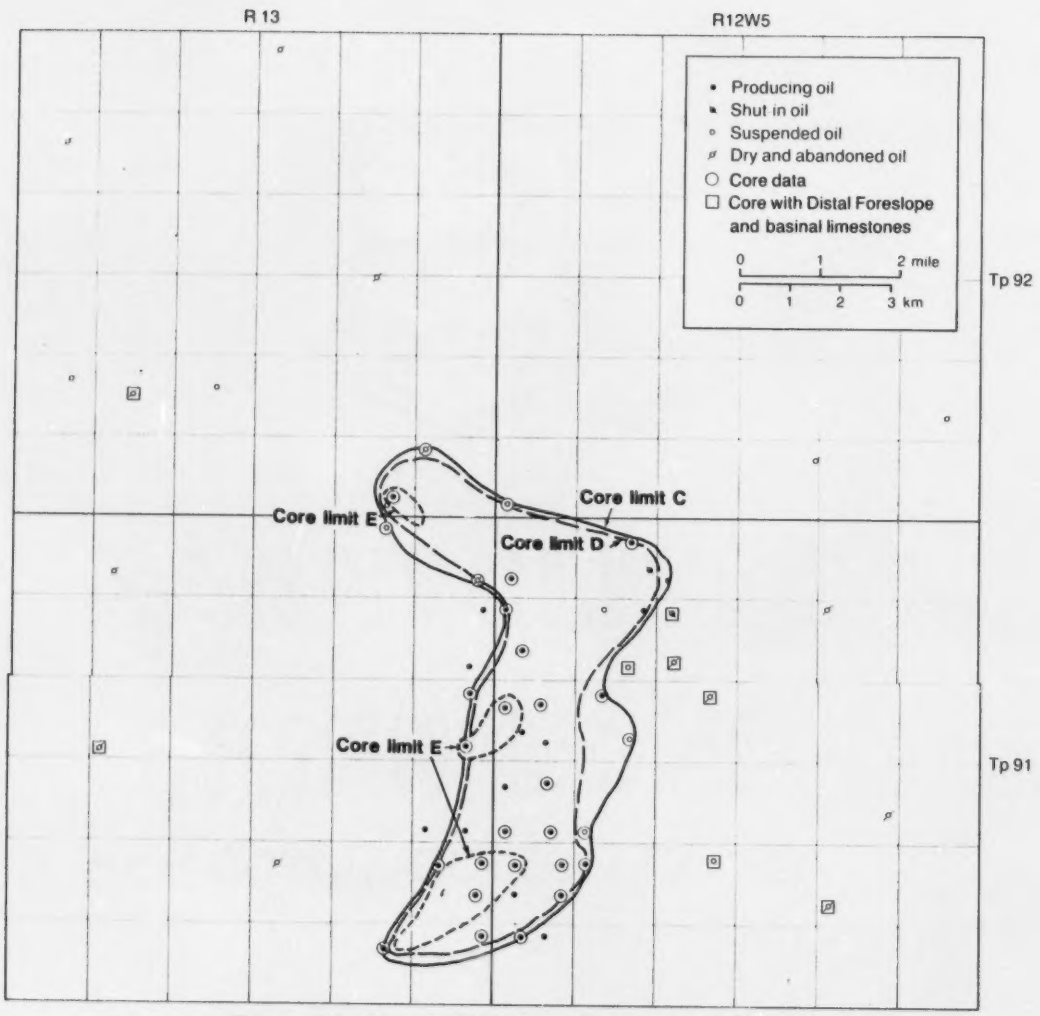
Distribution

Division D covers a smaller area than Division C, being locally absent on the eastern side of the field (Fig. 4.14). The thickness of the division averages 10.3 m in the north, 4.3 m in the center, and 6.3 m in the south (Fig. 4.3). In the north part of the field, Division D is thickest where Division C is the thinnest. Conversely, in the central and south portions of the field, Division D is thinnest where

Figure 4.14

Core limit of Division C, D and E

This is a location map that outlines the on-field occurrence, in core, of Division C, D and E. The off-field wells that have a square drawn around them represent core that were identified as containing distal foreslope to basinal limestones. These off-field sediments are probably equivalent to Division C, D and E on-field. Division C, D and E could not be traced to the off-field because of the change in facies to basinal sediments that obscured identification of the contacts between divisions.



Core Limit of Division C, D, and E

Division C is the thickest. This pattern suggests that Division D filled the topographic lows on the upper surface of Division C (Fig. 4.3).

Facies Succession

Division D consists of facies successions D-1 and D-2, that are restricted to the north-central and south parts of the field, respectively. Facies succession D-1 consists of Facies 11, Facies 8, and Subfacies 9a or 9b (Fig. 4.15). Facies succession D-2 consists of Subfacies 7b, Subfacies 7a, and Facies 6 (Fig. 4.16).

The upper contact of Division D represents the top of the Slave Point Formation where it is not overlain by Division E (Fig. 4.3). This contact consists of a planar (Fig. 4.5b) and hummocky (Fig. 4.5d) hardground.

Interpretation

In facies succession D-1, the massive lime mudstones (Facies 11) are thin (1.1 m to 2.9 m thick) and have a discontinuous distribution across the field. The fine-grained dark-coloured matrix, lack of *in situ* fauna, and the lack of evidence for subaerial exposure indicate a predominantly low-energy, subtidal environment of deposition (Fig. 4.15). The lack of current- or wave-related sedimentary structures and *in situ* shallow-marine fauna in the mudstones (Facies 11) is suggestive of deposition in deep-subtidal waters, situated below fairweather wave base or the base of the euphotic zone. Water depths were probably around 20 m to a few tens of meters.

The transition from facies (Division C) deposited in shallow-marine

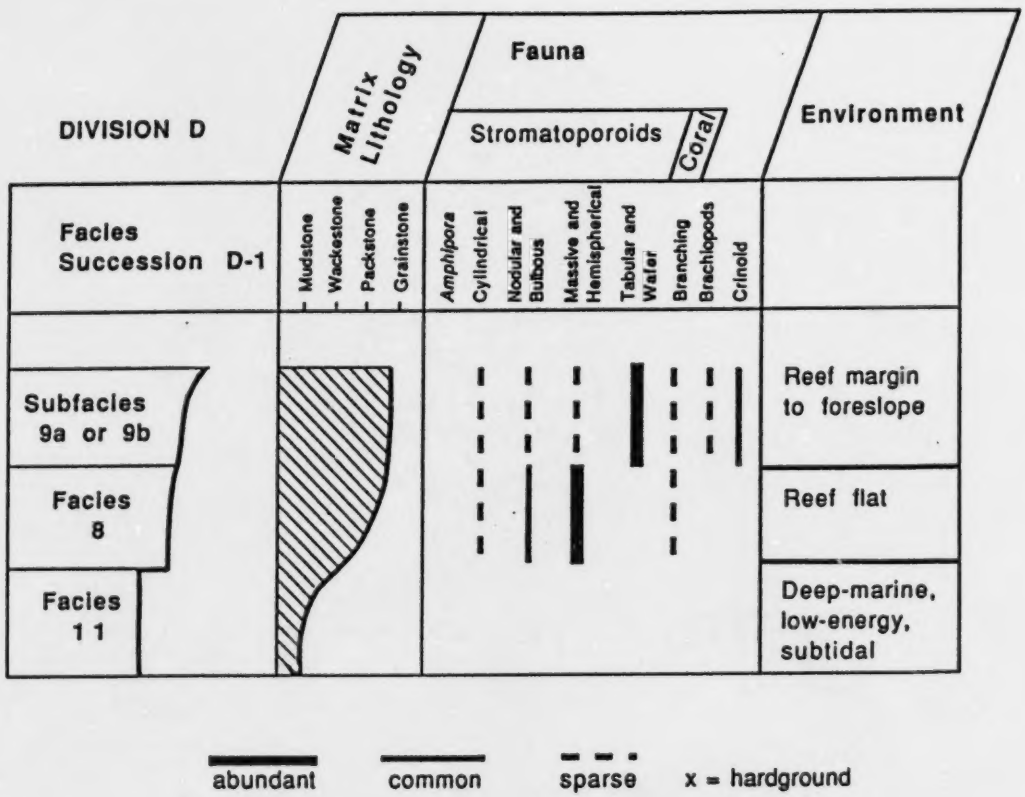


Figure 4.15 Schematic representation of Division D, facies succession D-1.

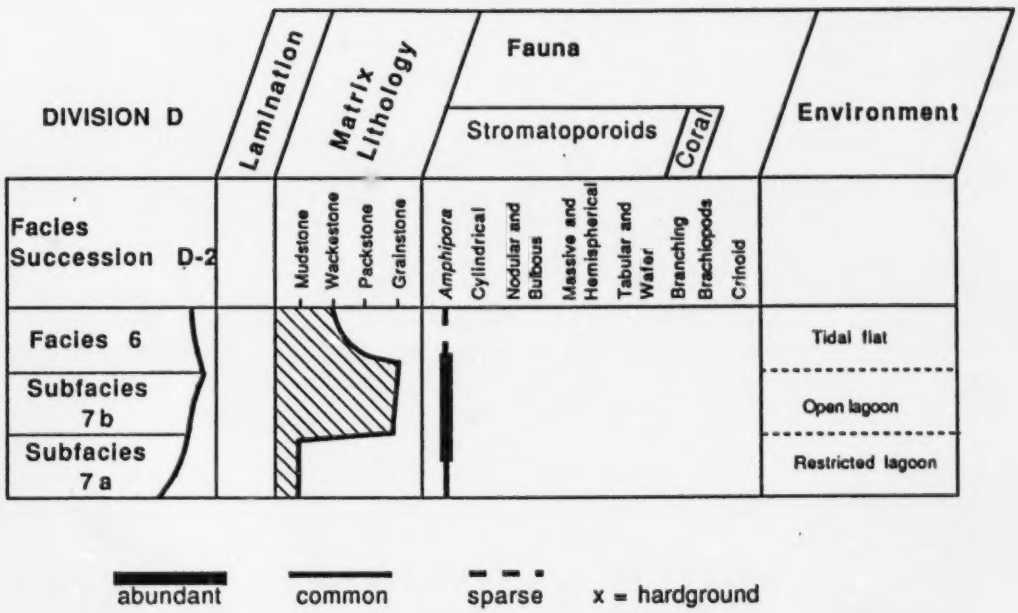


Figure 4.16 Schematic representation of Division D, facies succession D-2.

waters (between low tide and fairweather wave base) to facies deposited in low-energy, subtidal conditions (Facies 11) may be the result of a relative sea level rise. A relative rise in sea level would have caused deeper water conditions that exceeded the vertical growth potential of the shallow-marine facies in Division C (Facies 8 and Subfacies 9a). The lagoon (Facies 6 and 7) and margin (Facies 9b) environments of Division C, however, are overlain with shallow-marine sediments of Division D and not with deeper-water mudstones (Facies 11). The absence of mudstones (Facies 11) may be a function of the generally fast growth potential in the lagoon and margin environments (Kendall and Schlager, 1981; Wendte and Stoakes, 1987) that would keep pace with an increase in the rate of relative sea level rise.

Reef flat

In facies succession D-1, the interlocking subspherical stromatoporoids and exclusion of delicate stromatoporoid morphotypes in the matrix-free intervals of Facies 8 is suggestive of deposition in high-energy conditions, above fairweather wave base (Fig. 4.15). These conditions and presence of hemispherical stromatoporoids (Fig. 4.12) are indicative of deposition in a reef flat setting. Locally, a fine-grained matrix and floatstone texture is indicative of more moderate-energy conditions. In Division D, Facies 8 represents deposition in moderate- to high-energy conditions of the reef-flat that are laterally transitional with the margin (Facies 9b) and lagoon to tidal flat settings (Facies 6 and 7).

Reef margin

The encrusting, binding and robust nature of the thick tabular stromatoporoids in Subfacies 9b, that gradationally overlie and laterally interfinger with Facies 8 in facies succession D-1, represent deposition in moderate- to high-energy, well-circulated conditions of the reef margin (Fig. 4.15). Tabular stromatoporoids are considered to inhabit the margin based on their thick, robust shape (Fig. 4.14). The reef margin, primarily associated with Subfacies 9b, are located in the north and along the eastern flank of the field.

Reef foreslope

The predominantly fine-grained, bituminous matrix and thin, fragile form of the wafer stromatoporoids in Subfacies 9a, that overlie and laterally interfinger with Facies 8 and Subfacies 9b of Division D, represent low to moderate-energy conditions (Fig. 4.15). Wafer stromatoporoids are considered to inhabit the foreslope environment (Longman, 1981). The foreslope deposits would be characterized by deposition between normal to stormweather wave base and water depths in the order of 10 m to a few tens of meters (Fig. 4.11). The foreslope environment of Division D, primarily associated with Subfacies 9a, is located in the northeast and along the eastern edge of the field.

Reef interior

Gradationally overlying the reef interior of Division C is facies succession D-2 consisting of Facies 7 overlain by Facies 6 (Fig. 4.16). Locally, facies succession D-2 occurs twice in a single location (11-12-91-12W5, Fig. 4.7). In Subfacies 7b, the bituminous content,

dark colour and low diversity of fauna, dominated by *Amphipora*, is indicative of deposition in a restricted lagoon, characterized by low-energy and abnormal salinities (Fig. 4.16). In Subfacies 7a, the greater abundance of *Amphipora* (Fig. 4.12), absence of bituminous material and lighter colour of the matrix in comparison to Subfacies 7b, is suggestive of deposition in an open lagoon (Fig. 4.16). The presence of fenestrae, algal-laminae, and paucity of fauna in Facies 6 is indicative of deposition in a tidal-flat setting (*cf.* Wong and Oldershaw, 1980). The lagoon (Facies 7) and tidal-flat (Facies 6) are located in the extreme southwest part of the field.

The facies of Division D represent aggradation of an isolated reef. Facies succession D-1 consists of reef flat, reef margin, and foreslope environments, while succession D-2 consists of the reef interior. The depositional environments in Division D occur in approximately the same areal positions as observed for the reefal environments of Division C (Fig. 4.13). The submarine hardground capping Division D represents a depositional hiatus. This contact represents the top of the Slave Point Formation and corresponds to a rapid transgressive pulse that occurred at the end of the Givetian (Johnson *et al.*, 1985).

4.2.5 DIVISION E

Distribution

Division E has a discontinuous distribution along the western side of the field, being 3.0 m thick in the north, 2.7 m in the center, and 4.9 m in the south (Fig. 4.14).

Facies Succession

The facies succession in Division E, consists of Facies 11 gradationally overlain by Subfacies 2b (Fig. 4.17). These facies consist predominantly of mudstones, wackestones and minor packstones. Subfacies 2b contains a low- to moderate-abundance of moderately-diverse calcareous fauna (Fig. 4.17).

Interpretation

The fine-grained dark-coloured matrix, lack of *in situ* fauna, and the lack of evidence for subaerial exposure in Facies 11 is indicative of a low-energy, subtidal environment of deposition (Fig. 4.17). The lack of current or wave related sedimentary structures in the mudstones (Facies 11) is indicative of deposition below fairweather wave base or the base of the euphotic zone and in water depths from 20 m to a few ten's of meters. The massive mudstones (Facies 11) may have been deposited in deeper-water conditions than the underlying lagoon (Facies 6 and 7) and margin (Facies 9) environments of Division D. This transition from shallow-water facies in Division D to the low-energy, subtidal mudstones (Facies 11) of Division E may be the result of adverse environmental conditions and/or a relative rise in sea level. In either case, termination of shallow marine carbonate production in Division D occurred.

The association of crinoids, mostly intact brachiopods, and ostracods in Subfacies 2b is suggestive of low-energy conditions (Fig. 4.17). The local development of laminations, nodular texture and carbonaceous matter are also indicative of low-energy conditions. The nodular texture resulted from a combination of burrowing and selective

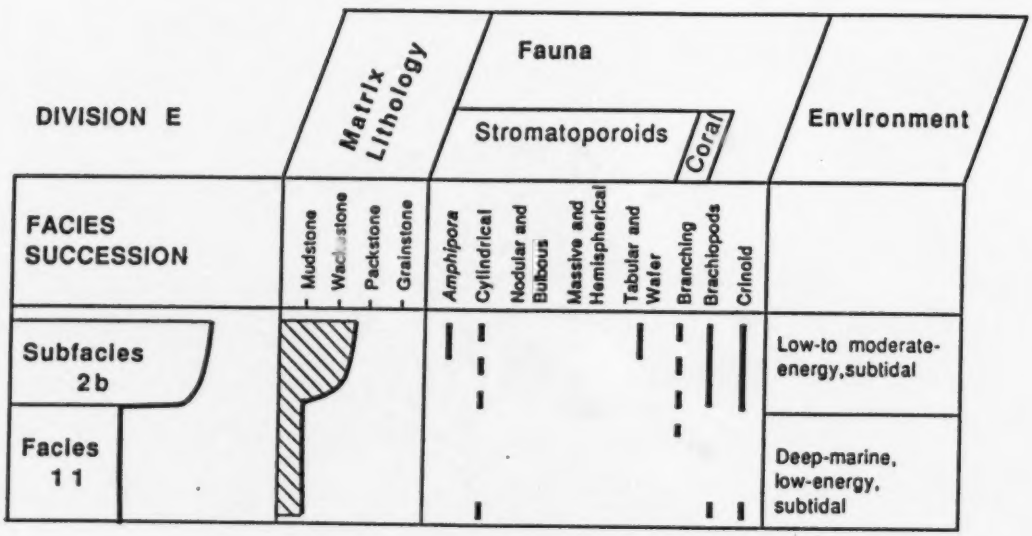


Figure 4.17 Schematic representation of Division E.

abundant common sparse x = hardground

early cementation accentuated by later compaction. Deposition occurred below fairweather wave base, in intermediate to deep water depths, as there are no current or wave-related sedimentary structures preserved. The local presence of abraded branching and tabular stromatoporoids indicate that moderate- to high-energy conditions, perhaps due to storm activity, transported and abraded the stromatoporoids.

The facies of Division E represent the capping sediments of the isolated reef (Division C and D). These sediments were deposited in intermediate- to deep-subtidal waters, perhaps after an increase in the rate of relative sea level rise that terminated deposition of Division D. Deposition of shallow-marine facies, that were identified in Division C and D, were not reestablished in Division E, suggesting that water-depths remained below the euphotic zone and/or adverse environmental conditions did not allow for their development.

4.3 CORRELATION OF DIVISIONS TO THE OFF-FIELD

The Slave Point Formation limestones on-field are primarily indicative of deposition in shallow-marine waters, located between low tide and fairweather wave base or the base of the euphotic zone. Conversely, the off-field limestones are indicative of deposition in deep-subtidal waters, situated below fairweather wave base or the base of the euphotic zone. The correlation of these lithologically contrasting limestones is difficult because limited subsurface well control does not provide a two-dimensional surface of their interfingering relationship.

Division A is the only unit that was easily traced to the off-field, which is a function of its deposition in stable, low-energy conditions

in a carbonate platform setting (Fig. 4.3). In the off-field, Subfacies 2b overlies Division A and consists of mudstones and wackestones containing abundant skeletal debris grading to unfossiliferous darker-coloured mudstones and wackestones (Fig. 4.6, 11-8-92-13W5). The off-field area east of the Sawn Lake field, is represented by the mud-supported facies (Subfacies 2b) of the offshore basin while the off-field area west of the field, is represented by the mud-supported facies (Subfacies 2b) of the inshore basin. Read (1985) considered inshore basins of rimmed platforms to have water depths of a few ten's of meters and to lie between fairweather and storm wave base. The off-field sediments in the offshore basin were probably deposited in slightly deeper-water conditions, however, lithological differences between the inshore and offshore basinal sediments (Subfacies 2b) were not noticeable in core. Stacked hardgrounds commonly occur in the upper part of Subfacies 2b (Fig. 4.7, 15-9-91-12W5) and represent periods of non-deposition that may be equivalent to the deposition of strata comprising a division on-field. Therefore, off-field hardgrounds may be correlative to the basal strata of Division B, C, D and/or E on-field.

4.4 DEPOSITIONAL HISTORY

4.4.1 Introduction

The Givetian Slave Point Formation was deposited during an overall eustatic rise in sea level and punctuated by a number of smaller pulses of relative sea level rise (Moore, 1988). Two to three periods of accelerated rates of relative sea level rise are documented in the development of Slave Point Formation fields around the Peace River Arch (Dunham *et al.*, 1983; Davies and Tooth, 1987; and Gosselin

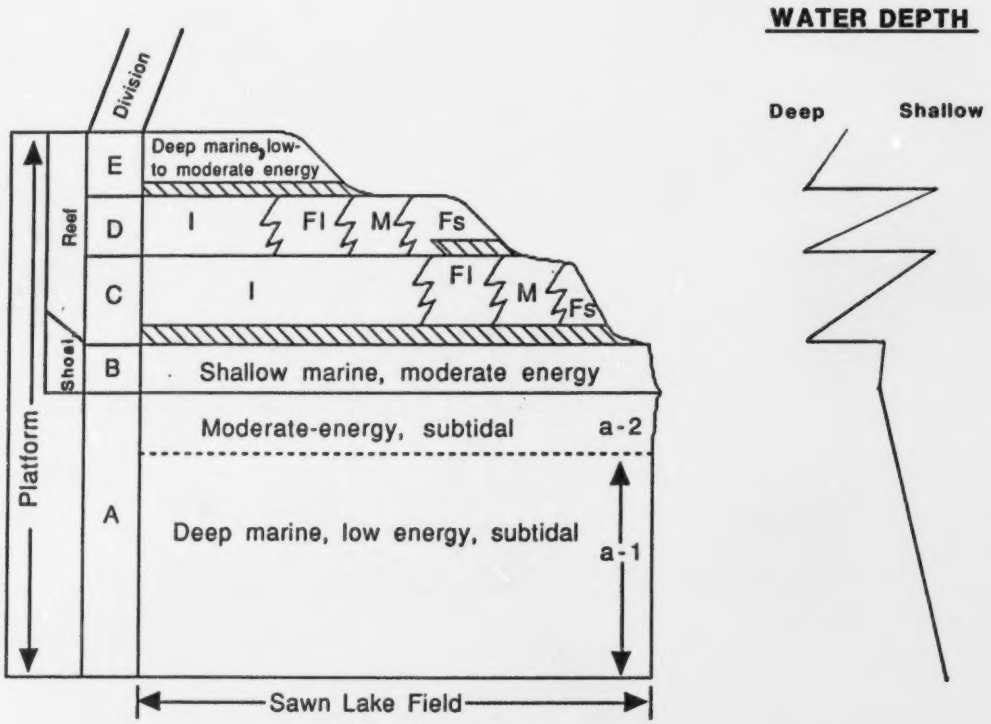
et al., 1989). At Sawn Lake, at least three accelerated rates of relative sea level rise may have occurred during deposition of the Slave Point Formation. These accelerated periods of relative sea level rise occurred at the base of Division C, D, and E and may have been controlled by an extrinsic or allocyclic mechanism (Fig. 4.18). An allocyclic mechanism would include the sum of eustatic sea-level changes, sedimentation and tectonic movement in the basin.

Division A - Carbonate Platform Development

Deposition of the laminated and nodular limestones (unit a-1) of Division A occurred in intermediate- to deep-subtidal waters (20 m to 10's of meters), characterized by low-energy conditions. The deposition of the abraded stromatoporoid packstones (unit a-2) occurred in moderate-energy conditions and intermediate water depths. The widespread distribution of unit a-1 from field to off-field areas and the homogeneous lithology of the limestones in Division A represent deposition in a carbonate platform setting (Fig. 4.18).

Division B - Carbonate Shoal Development on the Platform

Development of the branching corals and stromatoporoids (Facies 4 and 5) occurred in intermediate to shallow-marine waters (10 to 20 meters), in low- to moderate-energy conditions (Fig. 4.18). The facies of Division B, characterized by detrital sediment and fauna deposited in intermediate- to shallow-marine water depths, relatively close to their position of growth, represent deposition of a carbonate shoal. The development of a carbonate shoal (Division B) at Sawn Lake was probably initiated due to a subtle pre-Slave Point Formation paleotopographic



Depositional Environments

Rimmed-platform reef

I Interior
Fl Flat
M Margin
Fs Foreslope
Low-energy, subtidal

Figure 4.18 Schematic diagram summarizing Slave Point Formation sedimentological evolution at Sawn Lake.

high originating at the Precambrian. At the top of Division B, the environment was influenced by adverse conditions and/or an increase in the rate of relative sea level rise, that led to the cessation of carbonate production of the carbonate shoal (Fig. 4.18).

Division C: Platform Reef Initiation and Aggradation

A dramatic change in sedimentation occurs across the Sawn Lake field at the top of Division B. Deposition of the massive lime mudstones (Facies 11) occurred in low-energy, subtidal conditions following a change in environmental conditions and/or an increase in the rate of relative sea level rise (Fig. 4.18). These mudstones gradually grew upwards to shallow-marine waters that supported the development of branching corals and cylindrical stromatoporoids. These lowermost facies in Division C represent deposition of a carbonate shoal. The stromatoporoids and corals were, in turn, replaced by tabular stromatoporoid bindstones and rudstones (Facies 9) in more turbulent conditions of the reef margin, located in the north and along the eastern edge of the field. The margin had the effect of sheltering the reef-flat, consisting of subspherical stromatoporoid floatstones and rudstones (Facies 8), on the leeward side of the reef-margin, and reef-interior, consisting of *Amphipora* (Facies 7) and tidal-flat (Facies 6) limestones in the southwest part of the field. The reef-foreslope, consisting of wafer stromatoporoid floatstones (Subfacies 9a) and skeletal grainstones (Facies 10), developed on the windward side of the margin. An increase in the rate of relative sea level rise led to the termination of the reef-flat and foreslope environments (Fig. 4.18).

Division D: Platform Reef Aggradation

Following the preceding influence of locally adverse environmental conditions and/or relative rise in sea-level, lime mudstones (Facies 11) were deposited over the reef-flat (Facies 8) and foreslope (Subfacies 9a) environments of Division C. However, the vertical accumulation rate of the fast growing lagoon (Facies 7) and reef-margin (Facies 9) environments of Division C were not affected by the changes in the environment. Deposition of these faster growing facies in Division C continued directly upwards into Division D. An increase in the rate of relative sea level rise led to the termination of the isolated platform reef represented by Division D (Fig. 4.18).

Division E: Termination of the Isolated Platform Reef

Following the preceding relative sea level rise the mudstones (Facies 11) were gradually replaced by nodular and skeletal mudstones and wackestones (Subfacies 2b) representing low-energy, subtidal conditions (Fig. 4.18). These conditions occurred below fairweather wave base and represent the termination of the isolated platform reef at Sawn Lake field. Division E was terminated by a depositional hiatus and overlain by the Waterways Formation shales.

CHAPTER 5: POROSITY DISTRIBUTION

5.1 INTRODUCTION

The Slave Point Formation at Sawn Lake is characterized by heterogeneous porosity. Much of this heterogeneity can be attributed to the wide range of facies variations over the field (Fig. 5.1). In general, the facies of Sawn Lake contain good preservation of primary porosity. The primary porosity was partly dependent on the amount of fine-grained sediment in the matrix which was influenced by the current- and wave-energy occurring during deposition. At Sawn Lake, the facies deposited in higher-energy conditions commonly contained less fine-grained sediment and are characterized by higher porosities. Exceptions in higher-energy conditions include the deposition of rudstone and bindstone textures which are matrix-free and lack primary porosity. In contrast, the facies in Sawn Lake deposited in lower-energy conditions are predominantly fine-grained and have lower porosities.

5.2 POROSITY DISTRIBUTION IN THE DIVISIONS

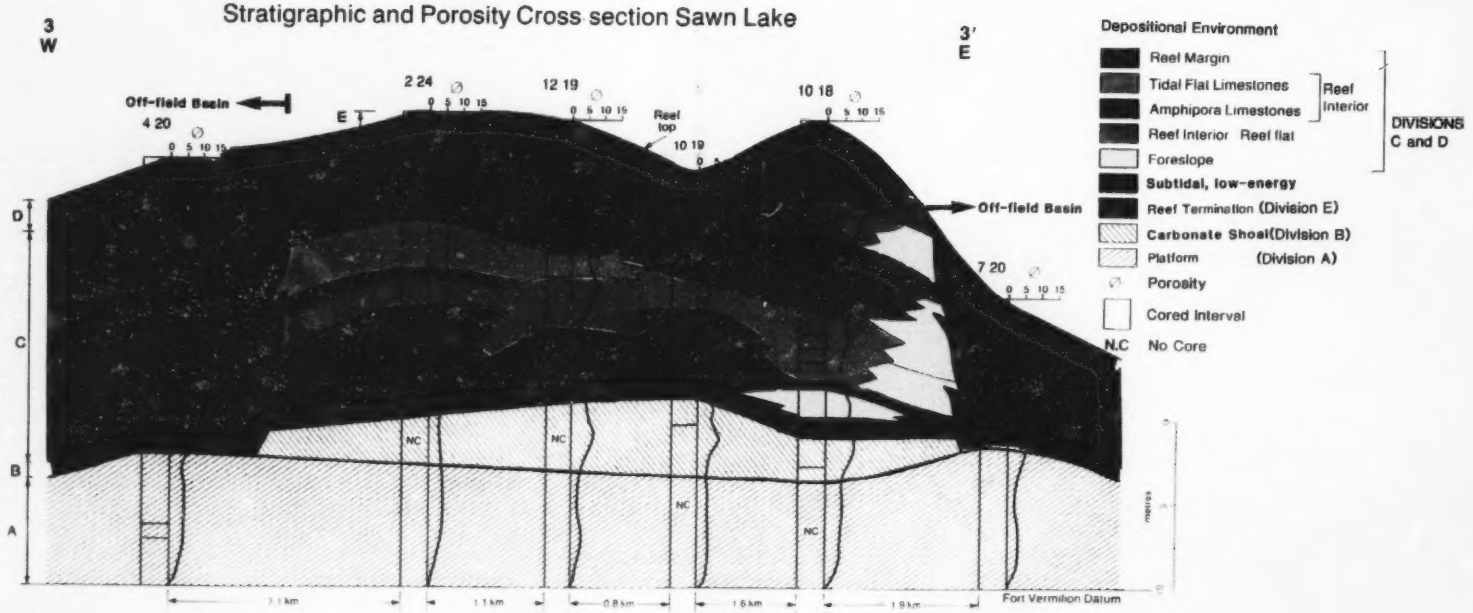
5.2.1 Division A

The fine-grained limestones of Division A, deposited in low-energy conditions, are characterized by poor (2 to 3%) porosities (Fig. 5.1). The slight increase in porosity in the middle part of Division A is due to intergranular porosity in the partly peloidal matrix of Subfacies 2a (Fig. 5.1). Poor vertical permeability in Division A (Facies 1 and Subfacies 2a) is a result of horizontal microstylolites which separate thin limestone beds. In general, Division A does not represent

Figure 5.1

Stratigraphic and porosity cross-section 3-3' across Sawn Lake

Stratigraphic cross-section of the Slave Point Formation, through the central area of the Sawn Lake field, illustrating the distribution of divisions, depositional environments and/or conditions, and porosity amount. The datum, at the base of the section marks the base of the Slave Point Formation and top of the Fort Vermilion Formation. Delineation of divisions are located on the far left. Each well is partially cored (bars) and short horizontal lines in each bar denote changes in lithofacies. The curve to the right of the bar indicates the amount of porosity, with scale (%) at top. The correlation of depositional environments between wells is interpretative. Massive mudstones (Facies 11) on-field are coloured dark brown and are interpreted to have been deposited in subtidal, low-energy conditions. The off-field area (in direction of arrows) also coloured dark brown are interpreted to have been deposited under similar conditions. Distances between wells are shown along the bottom of section in kilometers (km). The cross-section location is shown on Fig. 4.2.


Stratigraphic and Porosity Cross section Sawn Lake
3
W
3'
E
Off-field Basin
4 20
2 24
E
12 19
Reef top
10 19
10 18
Off-field Basin
7 20
D
C
B
A
NC
NC
NC
NC
1.1km
1.1km
0.8km
1.6km
1.9km
Fort Vermilion Datum
Depositional Environment
Reef Margin
Tidal Flat Limestones
Amphipora Limestones
Reef Interior Reef flat
Foreslope
Reef Interior
DIVISIONS C and D
Subtidal, low-energy
Reef Termination (Division E)
Carbonate Shoal (Division B)
Platform (Division A)
Porosity
Cored Interval
N.C No Core

reservoir-quality limestone.

5.2.2 Division B

In Division B porosity development is poor to moderate and directly reflects deposition in low- to moderate-energy conditions. Low to moderate porosity (3 to 6%) in the branching coral floatstones and rudstones (Facies 4) is a function of the bituminous wackestone and packstone matrix (Fig. 5.2c). The middle part of the division consists of better intergranular porosities (4 to 9%), which occur in the cylindrical stromatoporoid packstones and grainstones (Fig. 5.1). The upper part of Division B consists of lower porosities (5%) reflecting the predominantly rudstone texture and lack of matrix in Facies 5. Stromatoporoid galleries are filled with blocky calcite spar and do not contribute to the porosity (Fig. 5.2 d). In general, the facies of Division B represent a poor to moderate reservoir-quality limestone.

5.2.3 Division C

Porosity development in Division C varies from poor to excellent, reflecting the wide range of depositional facies variations across the field. The massive mudstones (Fig. 5.2b) deposited in the lower part of Division C have poor porosity (2 to 4%) and would act as an effective permeability barrier with the underlying facies of Division B.

In the upper part of the division, the best reservoir-quality limestones occur in the foreslope, reef margin (10-18 in Fig. 5.1) and parts of the reef flat (12-19 in Fig. 5.1). The foreslope and reef margin settings that contain the peloidal grainstones represent the most attractive reservoir limestones in the field. In the upper and middle

Figure 5.2

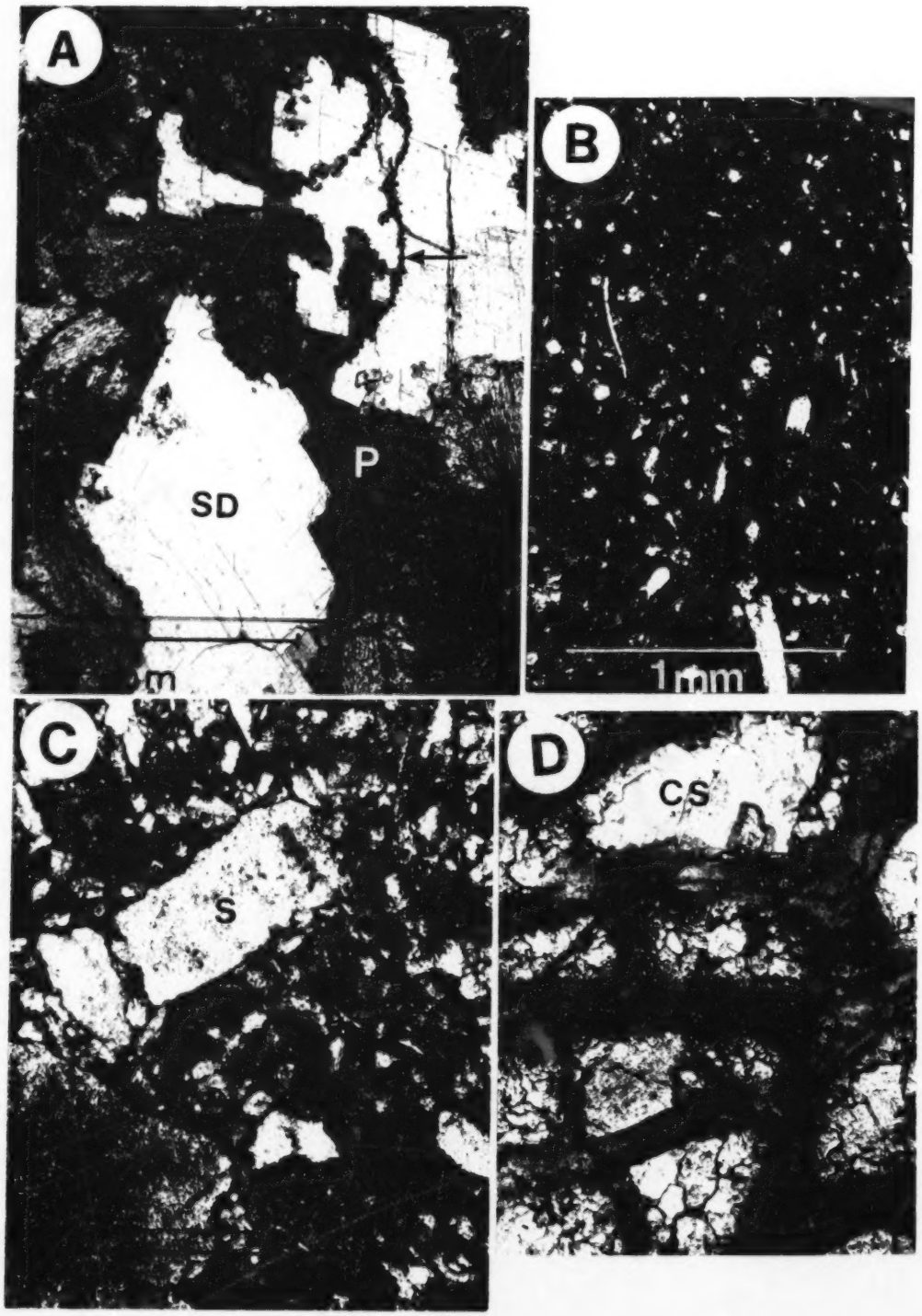
Photomicrographs of Facies

a) Photomicrograph of thick tabular stromatoporoid floatstone and bindstone (Subfacies 9b) in a reef margin position showing dissolution of bioclast and remaining shell fragment with micrite envelope (arrow). Resulting moldic porosity (P) and subsequent isopachous linings coat shell fragments. Voids and shell fragments partially filled with saddle dolomite (SD) cement. Sample from 16-29-91-12W5, 1593 m. Plane polarized light. Scale bar is 1 mm.

b) Photomicrograph of laminated lime mudstone (Facies 1) consisting of dark black stringers of organic material and abundant calcite cement (white blebs). Sample from 11-7-91-12W5, 1625 m. Plane polarized light. Scale bar is 1 mm.

c) Photomicrograph of branching coral floatstone (Facies 4) abundant, inclusion-rich, calcite cement (S). Sample from 9-7-91-12W5, 1621.6 m. Plane polarized light. Scale bar is 1 mm.

d) Photomicrograph of coral galleries filled with calcite spar (CS), equant calcite and isopachous cement in the branching coral floatstone (Facies 4). Sample from 9-7-91-12W5, 1621.6 m. Plane polarized light. Width of photomicrograph is 1.5 mm.


A
SD
P
m
B
1mm
C
S
D
CS

foreslope (Subfacies 9a and Facies 10) porosity consists of intergranular and moldic types. In the reef margin (Facies 9) porosity consists of intergranular, moldic (Fig. 5.1a), and shelter cavity (Fig. 3.10b) types. In the reef flat (Facies 8) better porosities occur in the skeletal, peloidal grainstones as intergranular and moldic forms. Conversely, lower porosities in the reef-flat occur where it is dominated by fine-grained wackestones and packstones (10-19-91-12W5 in Fig. 5.1).

In the upper part of Division C poor to fair porosities (2 to 5 %) occur in the lower foreslope and reef-interior (Fig. 5.1) limestones (Facies 7). The reef-interior, well-developed in the southwest part of the field, was deposited in low-energy conditions. The lower foreslope environment, characterized by poor to moderate porosities (3 to 6%) was deposited in low- to moderate-energy conditions where skeletal and sandy material in Subfacies 9a generally decreases downslope.

5.2.4 Division D

Porosity distribution in Division D is similar to that in Division C because of the development of equivalent depositional environments. The lower part of Division D is characterized by low-energy, subtidal mudstones having very low-porosity (Fig. 5.1). However, in the north and south parts of the field the lower part of Division D consists of shallow-water, coarser-grained sediments. The reef margin (Subfacies 9b), parts of the reef-flat (Facies 8) and foreslope (Subfacies 9a) contain the highest porosities (5 to 10%) and were deposited in moderate- to higher-energy conditions. The reef-interior (Facies 6 and 7) and parts of the reef-flat (Facies 8) adjacent to the lagoon contain

the lowest porosities (2 to 5%) and were deposited in lower-energy conditions.

5.2.5 Division E

Porosity distribution in Division E is generally of poor quality. Division E consists predominantly of low-energy mudstones (Facies 11) and wackestones (Subfacies 2b) that are characterized by low porosity (2 to 4%). However, the wackestones (12-19-91-12W5 in Fig. 5.1) commonly indicate moderate to good porosities (5 to 8%) that may reflect microporosity. The microporosity is characterized by very low permeabilities and would not represent reservoir-quality limestones.

CHAPTER 6: CONCLUSIONS

1. The Slave Point Formation at Sawn Lake is divided into 11 facies and 5 depositional units (Divisions A to E).

2. The upper surface of Division B, C, D, and E may represent deposition during an accelerated rise in relative sea level.

3. The lowest depositional unit, Division A, represents development of the Slave Point Formation carbonate platform. The shallow-water facies of Division B represent development of a carbonate shoal. Division C and D represent the aggradation of an isolated platform reef. Termination of the platform reef is represented by deposition of the deeper-water facies of Division E. Basin filling with marine calcareous shales (Waterways Formation) terminated deposition of Division E.

4. There is a good correlation between depositional environment and porosity. The best development of porosity occurs in parts of the reef flat, reef margin, and reef foreslope (Division C and D) that consist of matrix-supported peloidal-grainstones.

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